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Growing seed

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AZOLLA: CHEAP AND FEED SUPPLEMENT TO LIVESTOCK

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Azolla is a free-floating aquatic pteridophyte found worldwide in tropic and temperate fresh water ecosystems. It belongs to the family of salviniaceae. It appears as a green mat over water surface. Azolla fern hosts a symbiotic relationship with blue green algae (BGA) *Anabaena azollae,* an extracellular endosymbiont which is responsible for the fixation and assimilation of atmospheric nitrogen. Both the partners are photo-synthetically competent but the fern provides photosynthates to the BGA while the cyanobiont meets the N_2 requirement of the association. This association is outstanding because of its high productivity coupled with high rate of nitrogen fixation, equivalent to around 25 kg/ha, generally, it multiplies asexually though splitting methods, but sexual reproduction through spore formation has also been observed. Azolla *Microphylla* and A. *pinnata* are most commonly grown species and other species of Azolla are Filiculoides, Caroliana, Rubra and Maxicana.

It is commonly seen floating on water surface of flooded rice fields, small pound and other water reservoirs. Azolla can serve as an excellent N_2 bio-fertilizer for paddy crop as it forms an ideal environment for its growth. One or more species of Azolla are found naturally in almost every geographical area where lowland rice is grown. It is quick multiplication and doubles its biomass in 5-10 days, depending on climatic conditions, and yield can reach 8.5-10.5 tones fresh matter/ha in Asian paddy fields (Table.1).in a study 37.8 t fresh weight/ha (2.78 t DM/ha) has been reported from *Azolla pinnata* in India. Besides N_2 biofertilizer, Azolla has other multiple uses like biological herbicide, animal feed and as water purifier. Azolla farming, in general, is inexpensive due to high productivity and it can be multiplied in natural water bodies for production of biomass.

Nutritional value of Azolla

Azolla is very rich in proteins, essential amino acids, vitamins viz; vitamin A, vitamin B12, and minerals including calcium, phosphorous, potassium, ferrous, copper, magnesium. On a dry weight basis, Azolla contains 25-35% protein, 10-15% mineral, and combination of amino acids, bio-active substances and biopolymers 7-10%. Azolla is poor in carbohydrate, fatty acids.

Azolla is succulent of poor in fiber content (crude fiber 9.07 - 22.25%). On an average the ether extract value for various species varies between 1.60 - 5.05 % while total ash was in the range of 10.15-36.10% and NFE values varied between 30.08 - 52.46%. The variations in the nutrient composition of *Azolla* meal is due to differences in the response of *Azolla* strains to environmental conditions such as temperature, light intensity and soil nutrients which consequently affect their growth morphology and chemical composition. The cell wall composition of *Azolla* is highly variable depending upon the species and the season of cultivation of Azolla. Cellulose and hemicelluloses content range between 6.8 to 36.7% and 10.09 to 17.8 respectively.

Amino acid composition: The Azolla *microphylla* strain is a good source of amino acids and its composition is on given in table.

Table 1. Amino acid composition of Azolla meal

Amino acids	DM%	g /100g protein
Lysine	0.98	4.58
Methionine	0.34	1.59
Cystine	0.18	0.84
Threonine	0.87	4.07
Tryptophan	0.39	1.82
Arginine	1.15	5.37
Isoleucine	0.93	4.35
Leucine	1.65	7.71
Phenylalanine	1.01	4.72
Tyrosine	0.68	3.18
Glycine	1.00	4.60
Serine	0.90	4.21
Valine	1.18	5.51

Materials Pond Size and Construction

To grow azolla in 6X4 pond following silpauline sheets of 150 GSM or any other polythene sheet, sieved fertile soil, vermicompost, poultry manure, cow dung, powdered rock phosphate, culture of azolla and micronutrients.

Growing conditions:

Azolla Unit require regular upkeep and monitoring of the pond. The site should be under partial shade to reduce the evaporation of water and also, for better growth of Azolla. Water is the basic requirement for the growth and multiplication of Azolla and is extremely sensitive to lack of water Azolla absorbs the nutrients from water. water source should be nearby for regular water level maintenance. The species vary in their requirement of ideal temperature.

In general, azolla multiplies rapidly at the daily mean temperature of 15 ^{o}C to 30^{o}C. Azolla is sensitive to desiccation. Above 30 ^{o}C to 33^{o}C or below 10^{o}C, the growth is highly retarded. It prefers open/diffused light for photosynthesis and grows well in partial shade. in sunlight is needed for its normal growth and protation from during winter low temperature (<10 ^{o}C) is needed. Maintenance of adequate water level essential. The optimum relative humidity is 85 to 90 per cent.

The optimum pH is for azolla 5 to 7. High acidic or alkaline pH adversely of effect growth of this fern. Though all elements are essential, phosphorus is most limiting element for its growth. About 20 ppm of phosphorus in the water is optimum. In advance conditions viz. nutrient deficiency, bright light Azolla hot summer or cold winter, it also turns red or brownish red.

It can successfully be grown round the year in southern states like Karnataka, Kerala, Goa, Tamil Nadu and Maharashtra and during monsoon and summer months in states of Punjab, Haryana, Delhi, U.P., Bihar, M.P., Rajasthan, Gujarat, and Chhattisgarh. In hilly states where winter in pronounced, azolla can be grown only in monsoon and summer months.

Table 2. Biomass and doubling time Different Azolla species growth in poly house (at 30°C to 32°C)

Azolla spp.	Biomass (g) (fresh wt.)/g	Doubling time (days)
A. filiculoides	4-5	6-7
A. microphylla	5-6	5-6
A. pinnata	2-3	10-12
A. rubra	4-5	6-7
A. mexicana	4-5	6-7
A. caroliniana	5-6	6-7
A rubra	5-7	7-8

Pond size and construction: The size of pond depends on factors like number of animals, quantity of supplemental feed required and availability of resources. For small holders, an area of 6x4 feet for Azolla cultivation can produce about one kg of supplemental feed per day. Selected area should be cleaned and leveled. A water body of 2x1.5x0.4 m is dug and leveled to maintain uniform water. It is lined with a silpauline sheet/ any other polythene sheet. Silpauline is is resistant to the ultra violet radiation in sunlight. Width of the bed is maintained at 1.5 m to enable the cultural operation from both sides. The side walls of the pond can be of either bricks or raised embankment with the excavated soil.

Cultivation Technology

The methodology for economically cultivating *Azolla* by the livestock farmers is described here under:

- After spreading the durable plastic sheet in the pond, all the sides have to be secured properly by placing bricks over the side walls.
- About 10 – 15 kg of sieved fertile soil is uniformly spread over one sqm about 10 cm deep over the silpauline sheet. Slurry made of 5 kg of pre-decomposed (2 days) old cow dung and 30 g of super phosphate mixed in 10 liters of water, is poured onto the sheet. More water is poured on to raise the water level to about 20-25 cm.
- About 0.5 – 1 kg of fresh and pure culture of a*zolla* is inoculated in the water of the pit. it multiphy rapidly and make a green covers net over the pit within 10 – 15 days. From then on, 500 – 600 g of a*zolla* can be harvested daily. Biomass should be removed at regular interval of 4-5 days to avoid overcrowding and un interrupted growth.

- A mixture of 20 g of super phosphate and 1 kg cow dung should be added every 5 days to maintain rapid multiplication of the a*zolla*.
- About magnesium, iron, copper, sulphur nutrient of mix in made by mixing 10 kg rock phosphate, 1.5 kg magnesium salt and 500 g of murate of potash add 40g of it monthly intervals to enhance the mineral content of a*zolla*. This not only takes care of the micronutrient requirement of azolla but also the cattle when it is fed with the azolla.

Precautions

- For rapid multiplication periodic application of cow-dung slurry, super phosphate and other macro and micronutrients should be done.
- The temperature should be maintained below 28°C. If the temperature rises, the light intensity should be reduced by providing shade.
- The pH should be tested periodically and maintained between 5.5 and 7.5.
- About 5 kg of bed soil should be replaced with fresh soil, once in 30 days, to avoid nitrogen build up and prevent micro-nutrient deficiency.
- At every 10 days interval, 25 to 30 percent of the water needs to be replaced with fresh water.
- At every six months the bed should be cleaned, the water and soil replaced and new *Azolla* inoculated.
- In case of pest and diseases infestation a fresh bed has to be prepared and inoculated with pure culture of *Azolla*.
- The *Azolla* should be washed in fresh water before use, to remove the smell of cow dung and other smell.

Insects: Insect damage is one of the major problems in the tropics. Lepidoptera, Pyralidae larva are most harmful insect pests to azolla. At higher temperature around 30ºC, the damage is severe, because azolla growth slows down while insect growth is active. In extreme cases, azolla mat in the field is eliminated within a few days by Pyralidae. The application of imidacloprid @5ml/1000 l water provides effective control of the insects

Utilization of Azolla in Livestock Feed

Though India stands first in the world in terms of milk production and bovine population, average production still needs to be improved. This may be due to low plane of nutrition due to insufficient availability of quality fodder/feed. It is also called as *Green gold mine* due to its high nutritive value and *Super plant* due to its fast growth. Azolla was found to be a very nutritive and cheap organic feed substitute for dairy cattle, poultry, pig, fish etc. In recent years, azolla has become prominent, because of its ability to concentrate minerals on heavily polluted water particularly arising from sewage treatment facilities. Coupled with its potential as a feed resource for livestock. For two cows, two units (beds length 2.5 m each with an area of around 8 sq m) utilization. to introduce Azolla, the fresh azolla should be mixed with commercial feed in 1:1 ratio to feed livestock. Field trial showed an overall increase of milk yield of approximately 15% when 1.5 - 2 kg of fresh azolla per day was supplemented with commercial feeds. Azolla feeding improves quality of milk, meat and improved in growth & development. Azolla can be fed to sheep, goat, pig as feed substitute and dried azolla meal can be incorporated up to 20 % of the concentrate mixture of kids without any adverse effect. Livestock can easily digest Azolla due to high protein content and low lignin content. Azolla feeding also improves the weight of broiler chicken and increasing the egg production in case of layer.

Advantages of Azolla Cultivation

1. It easily grows under controlled condition with very good yields.
2. t can easily be produced in large quantity in both the seasons – *Kharif* and *Rabi*.
3. It as fixes atmospheric CO_2 and nitrogen to form carbohydrates and ammonia respectively and after decomposition to help maintained C:N ratio in soil and increase the fertility of soil.
4. The oxygen released due to oxygenic photosynthesis, helps the respiration of root system of the crops as well as other soil microorganisms.
5. It solubilizes Zn, Fe and Mn and makes them available to the rice.

6. Azolla suppresses tender weeds such as Chara and Nitella in a paddy field.
7. Azolla releases plant growth regulators and vitamins which enhance the growth of the rice plant.
8. Azolla can be a substitute for chemical nitrogenous fertilizers to a limited extent (25 kg/ha) and it increases the crop yield and quality.
9. Improve seedlings or transplanted plant establishment and survival.
10. It reduces the rate of evaporation in irrigated paddy field improve drought tolerance by water less frequently.

Harvesting and Feedings of Azolla

Depending on the initial quantity of culture added, environmental conditions and nutrition, Azolla's growth in the pond is complete in about two to three weeks time. It can be harvested daily after the full growth. Plastic sieves (1 cm^2) can be used to harvest the biomass from the pond's surface. About 800 to 900 grams of fresh Azolla (mean yield per day in a season) can be produced from an area of 6 X 4 feet. Azolla can be fed to the livestock either in fresh or dried form. It can be given directly or mixed with concentrates to cattle, poultry, sheep, goat, pigs and rabbits. feeding of Azolla @ 800 grams (fresh weight) on an average per day, improved the monthly milk yield by at least 10 liters per cow. It takes a few days for the animals to get used to the taste of Azolla. After a fortnight of feeding on *Azolla* mixed with concentrate, livestock may be fed with soul *Azolla* or mixed with straw. So, it is better to feed it along with the concentrates in the initial stages. A farmer can realize a net profit of over Rs. 4000 per annum from the additional milk yield and reduced usage of concentrates' feeding for livestock. For poultry, *Azolla* can be fed to egg layers as well as broilers.

Conclusion

Azolla is also called as *Green gold mine* due to its high nutritive value and *Super plant* due to its fast growth. It was found to be a very nutritive and cheap organic feed substitute for dairy cattle, poultry, pig, fish etc. It has been well established that azolla can be grown for meeting organic cattle feed supplement in addition to use as Dual Culture in rice farming and bio-manure for crops, vegetables and plants for environmental conservation and economic returns.

Beyond its agricultural utility, Azolla contributes significantly to climate change mitigation. It rapidly sequesters carbon and helps lower methane emissions in rice cultivation systems. In addition, its capacity for bioremediation makes it useful in treating polluted water bodies. Emerging industrial applications-such as its potential use in biofuel and bioplastic production-further underscore its economic importance. However, large-scale utilization is hindered by limitations including short shelf life, high moisture content, and ecological risks associated with its invasive nature.

In essence, Azolla represents a cost-effective, eco-friendly solution with broad benefits across food security, climate mitigation, and environmental management. To fully harness its potential as a cornerstone of climate-smart agriculture, future efforts must focus on improving preservation techniques, establishing standardized practices, ensuring ecological safeguards, and advancing genetic and precision cultivation strategies.

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DARK FISHING FLEETS AND SATELLITE TRACKING: USING AIS DATA TO EXPOSE ILLEGAL FISHING

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Illegal, unreported, and unregulated (IUU) fishing pulls in a huge chunk of the world's catch. It messes with fisheries management, drains fish stocks, and robs coastal countries especially in the developing world of billions of dollars every year. The ships doing this are practically invisible. Plenty run as "dark fleets," switching off or messing with their AIS transponders on purpose just to avoid getting caught. But things are starting to change. Thanks to new satellite technology blending AIS data with synthetic aperture radar, optical satellite images, and even night time light detection, all crunched by machine learning the world is finally starting to see what's really going on out at sea. Turns out, most of the world's industrial fishing vessels just aren't tracked publicly most of the time. This article digs into how these dark fleets actually work and why they manage to keep operating. It looks at the cutting edge satellite and AI tools that are helping uncover their activities and what this means for enforcing protected marine areas, running fair fisheries, and protecting people's rights at sea. Case studies from Global Fishing Watch and other research show both how massive this problem really is and how open satellite data is finally making it a lot harder for illegal fishing to go unnoticed.

The ocean has always been tough to keep an eye on. On land, it's easy you can spot roads, buildings, and other infrastructure from satellites. But out at sea, figuring out who's fishing where, and whether they're following the rules, has usually depended on patchy reports from the people fishing, random chance encounters with patrol boats, and port inspections that only happen after a boat comes back. So, illegal, unreported, and unregulated (IUU) fishing takes advantage of that gap. Some estimates say IUU fishing makes up over 20% of the global catch, which throws off stock assessments, hurts legal fishers, and robs coastal countries often ones that really need the income and food supply of important resources. Then came the Automatic Identification System, or AIS. This tech was originally meant to stop ships from crashing into each other, but it turned out to be a game-changer for tracking where vessels go and figuring out where fishing happens, all across the globe. AIS wasn't built for keeping tabs on bad actors. Any vessel can just turn off its transponder whenever it wants. That's created a "dark" fleet of ships boats that disappear from the usual public tracking systems, making their activity nearly impossible to monitor. This article takes a closer look at how these dark fleets manage to operate in the shadows, how new satellite tools are starting to bring them out into the open, and what this new wave of transparency could mean for the future of managing our oceans.

What Are Dark Fleets, and Why Do They Persist?

Dark fleets are ships that don't share their locations through AIS. Sometimes they aren't required to carry a transponder, sometimes they turn it off on purpose, or they're just in places where satellite AIS signals can't reach. Global Fishing Watch found that most of the world's big fishing vessels aren't trackable at any given moment. This issue really stands out in Asia, where rules about AIS are all over the place and enforcement is pretty weak. There's a lot driving ships to go dark, and it's not just about illegal fishing. They go silent to hide while fishing inside marine protected areas, or when they drift into another country's exclusive waters without permission. Sometimes, they want to keep transhipment under wraps that's when they pass off their catch at sea, which is a sneaky way to launder illegal fish into the market. There's also the ugly reality of human trafficking and forced labour; most vessels flagged for forced labour don't use AIS at all, making it easier for them to stay off the radar and avoid scrutiny. Of course, not every "dark" ship is hiding something. Reception is a problem, too. Inshore and coastal areas, especially around Southeast Asia and Africa, have terrible satellite coverage. And in some countries, the government even blocks access to AIS data from their waters, so people can't see what's going on, even if the ships are trying to broadcast. It's not just fishing, either. Dark fleets pop up in all kinds of maritime activities. Satellite data has caught ships going dark to dodge international sanctions, like doing ship to ship transfers in violation of trade bans. The same tools used to uncover illegal fishing now help track wider security risks out at sea.

Satellite and AI Technologies Illuminating Dark Fleets

The Automatic Identification System, or AIS, is still the go to data source for tracking global fishing. Ships constantly send out updates on their position, speed, and heading, and when researchers combine billions of these messages, they can map fishing activity all over the world. It's a huge leap from those older, catch only estimates the detail is just on another level. Turns out, industrial fishing touches most of the world's oceans. Then you have synthetic aperture radar, or SAR. Unlike AIS, SAR satellites actually shoot radar down to the sea and pick up reflections so they can spot ships whether the crew wants to be seen or not.

Even if a vessel turns off its AIS, SAR can still find it. That makes SAR essential for catching "dark vessels" that would otherwise slip under the radar. Daytime optical imagery has its place, too. It helps confirm what radar picks up and gives a better look at what the vessels are doing. At night, some satellites can spot artificial lights on the ocean ideal for finding ships like squid jiggers or purse seiners that use bright lights to lure fish. These glowing signatures stand out, even if a ship isn't broadcasting AIS.

It's how scientists now pull all these streams together AIS, SAR, optical, and night time imagery and feed them into deep learning models. These models are trained not just to tell fishing vessels apart from other ships, but also to guess what kind of fishing is happening, even in parts of the ocean where AIS signals are sparse or missing. With this, researchers crunch through vast amounts of data petabytes, actually and produce near real time global maps of vessel activity. That just wasn't possible before. And here's the big shift, platforms like Global Fishing Watch now put much of this data out there for anyone to use. This open access was intentional, breaking down the old barriers where only governments or industry giants had this kind of insight. Now, journalists, researchers, and regular folks can dig into the same data, shining a light on potential illegal fishing anywhere in the world.

Implications for Governance and Enforcement

Satellite monitoring has started to shine a light on "dark vessels" sneaking into fully protected marine reserves. We're talking about places like the Galápagos Marine Reserve or the Great Barrier Reef Marine Park spots you'd hope are off limits for everyone, but some boats just keep crossing the line anyway. Even so, when you compare different marine protected areas, the ones with strict industrial fishing bans are mostly keeping poachers out. Satellite tech can catch people breaking the rules, and it proves that strong enforcement actually works. There's a whole other layer to this with transhipment at sea. This is when one vessel transfers its catch to a giant refrigerated cargo ship, far from any inspectors. It's perfect for mixing illegal fish in with the legal haul tough to trace once it reaches port. Now, satellites are helping track weird rendezvous patterns, tipping off authorities to suspicious transfers that need a closer look.

The human story is pretty bleak, too. A lot of vessels dodging AIS tracking (the system ships use to broadcast their location) are also linked to labour abuses, like forced work at sea. Researchers now pair satellite data with human rights know how to zero in on boats where crews are most at risk, so the benefits of watching these "dark fleets" stretch way beyond just policing fishing quotas. This kind of vessel tracking gives a solid backbone to international agreements, too. Countries finally have independent evidence for things like port inspections, regional fishery rules, or deals between coastal nations and far away fishing fleets. With this kind of proof, there's a real push to switch IUU (illegal, unreported, and unregulated) fishing enforcement from playing catch up with patrol boats to catching lawbreakers in real time with hard data. Still, spotting bad actors from space is just the first step. Catching them is a whole different struggle especially for small or developing coastal nations that just don't have enough ships or resources. Even after a satellite flags a vessel, some governments can't actually haul them in. And if the violation happens in international waters or someone else's territory, the legal and diplomatic headaches are far from over.

Policy and Future Directions

To make global fisheries more transparent, we need stronger rules. Industrial fishing vessels should be required to always carry and use AIS (Automatic Identification Systems), with real penalties if they mess with the equipment or don't follow the rules. On top of that, investing more in satellite radar especially ar0ound places like Southeast Asia where untracked "dark fleets" operate is crucial, since these regions remain blind spots. Sharing data also matters. When coastal countries can use satellite information about ships in their exclusive zones even if they don't have much monitoring tech of their own they stand a far better chance at stopping illegal activity. This kind of international data sharing deal can make small or under resourced countries much tougher enforcers. Open access platforms and better machine learning models play a big role too. The smarter and better trained these detection systems are, the easier it is to spot illegal fleets. So, public investment here shouldn't slow down. we need to make sure the evidence from satellites actually counts. That means regional fisheries groups and port authorities should start relying on satellite data as a formal part of their enforcement process. Without that step, all this new visibility won't translate into real accountability on the water.

Conclusion

When you bring together AIS data, synthetic aperture radar, optical and night time satellite imagery, and machine learning, you end up with a totally new window into what people are actually doing at sea. Suddenly, we know that most of the world's industrial fishing vessels are running outside the scope of public tracking right now, all the time. This sharper visibility is already making waves. It's transforming how marine protected areas get enforced, it's outing connections between illegal fishing, transhipment laundering, and even forced labour, and it's giving international fisheries rules more solid evidence to lean on. But spotting these vessels isn't the same as holding people accountable. Turning these streams of satellite data into real action is tough especially for coastal states that have limited resources and find themselves going up against huge, well-funded distant-water fleets. The technology keeps getting better, though. Its real potential isn't just to shine a light on hidden fleets. It's about using that new transparency to push for a fairer, more open, and more sustainable way of governing the world's oceans.

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APPLICATION OF HYDROGEL TECHNOLOGY IN SUSTAINABLE SOIL WATER MANAGEMENT FOR CLIMATE-RESILIENT FARMING IN ARID AND SEMI-ARID AREAS

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Climate change is making water scarcity, unpredictable rainfall, and soil degradation even worse in dry areas, which poses serious risks to farming and food security. That's why sustainable soil water management is crucial for farming systems that can withstand climate challenges. One exciting development in this area is hydrogel technology, especially the use of superabsorbent polymers (SAPs). These materials are proving to be a game-changer for keeping soil moist and boosting crop yields in drought-prone regions. Hydrogels are unique three-dimensional polymers that can soak up and hold a lot of water, releasing it slowly to plant roots as needed. When used in agricultural soils, they enhance water efficiency, cut down on how often irrigation is needed, reduce nutrient loss, and improve soil characteristics like porosity and stability. In dry environments where evaporation is high and rain is scarce, hydrogels help create the right moisture levels for seed germination, root growth, and overall crop development. Research has shown that integrating hydrogels with climate-smart farming practices can lead to significant yield increases in crops like pearl millet, maize, wheat, and various vegetables. Plus, there are biodegradable and eco-friendly hydrogels made from natural materials that provide sustainable options, helping to alleviate concerns about synthetic polymers piling up in the soil. However, there are still hurdles to overcome, such as high production costs, inconsistent performance in the field, and a lack of awareness among farmers, which can slow down widespread use. This review sheds light on how hydrogel technology can play a vital role in sustainable soil water management and its potential to support climate-resilient agriculture in areas facing water stress. Wider adoption, backed by research, policy changes, and educating farmers, could really boost agricultural sustainability and resilience as we face shifting climate conditions.

Water scarcity poses a significant challenge to agricultural productivity, especially in arid and semi-arid regions around the globe. With climate change ramping up the frequency of droughts, causing erratic rainfall patterns, and increasing evapotranspiration rates, we're seeing a troubling decline in soil moisture and crop yields (Oladosu et al., 2022). This makes sustainable soil water management crucial for boosting agricultural resilience and securing food supplies in the face of shifting climate conditions. Enter hydrogel technology, which has become a game-changer for conserving soil moisture in dry land farming. These superabsorbent polymer materials can soak up impressive amounts of water and then slowly release it to plant roots when they need it most (Krasnopeeva et al., 2022). By using hydrogels, farmers can enhance soil water retention, cut down on how often they need to irrigate, and improve crop performance even when water is scarce. Recent research has sparked a growing interest in eco-friendly and biodegradable hydrogels, thanks to their potential benefits for climate-smart agriculture. Not only do these hydrogels help retain soil moisture, but they also minimize nutrient leaching, enhance soil structure, and boost water-use efficiency (Li et al., 2022).

Agricultural Hydrogels and Their Functions

Hydrogels are fascinating three-dimensional networks of hydrophilic polymers that can swell up when they come into contact with water, all without dissolving. In the agricultural world, hydrogels are typically categorized into three types: synthetic, natural, and hybrid. Synthetic hydrogels are often made from polymers like polyacrylamide and polyacrylate, which are known for their impressive water absorption capabilities and durability in soil (Adjuik et al., 2022). On the other hand, natural hydrogels come from biodegradable sources such as starch, cellulose, chitosan, and alginate. These options are not only eco-friendly but are also gaining popularity in sustainable farming practices because they help minimize the environmental risks linked to synthetic materials (Li et al., 2022).

Hybrid hydrogels, as the name implies, blend both synthetic and natural polymers to enhance their water retention, biodegradability, and nutrient release features. Think of hydrogels as tiny water reservoirs nestled in the soil. When it rains or during irrigation, they soak up and store water, which they then release slowly to the plant roots during dry spells. This clever mechanism plays a crucial role in keeping soil moisture levels stable in the rhizosphere, ultimately helping to shield plants from drought stress (Krasnopeeva et al., 2022).

Role of Hydrogels in Soil Moisture Management

Hydrogels are incredibly important for boosting the water-holding capacity of soil, particularly in sandy areas that often struggle with low organic matter and poor moisture retention. When added to the soil, they enhance its porosity, aggregation, and infiltration, which ultimately makes more water available for crops (Oladosu et al., 2022). Research has shown that using hydrogels can significantly cut down on evaporation losses and improve how efficiently water is used. According to Adjuik et al. (2022), both bio-based and synthetic hydrogels have been found to enhance soil hydraulic properties by increasing water retention and minimizing losses from evaporation and deep percolation. Moreover, hydrogels play a key role in better nutrient management by reducing nutrient leaching and boosting fertilizer efficiency.

The water stored in hydrogels can dissolve nutrients and release them gradually along with moisture, ensuring that plants have a steady supply of nutrients (Li et al., 2022). In areas prone to salinity and drought, hydrogels can alleviate moisture stress and support better crop establishment. Tefera et al. (2022) noted that biomass-based hydrogels improved water retention and lessened salinity stress in salt-affected soils, which is vital for sustainable crop growth.

Hydrogels and Climate-Resilient Agriculture

Climate-resilient agriculture is all about boosting the ability of farming systems to adapt to climate-related challenges like drought and unpredictable rainfall. One exciting way to enhance this resilience is through hydrogel technology, which helps conserve soil moisture and keeps crop productivity steady even when water is scarce (Oladosu et al., 2022). Hydrogels play a crucial role in improving seed germination, root growth, and plant survival by ensuring that there's enough moisture around the roots during dry spells. This is especially vital in arid and semi-arid areas where irrigation options are limited and rainfall can be hit or miss (Krasnopeeva et al., 2022). Using hydrogels can also mean less frequent irrigation and better conservation of our precious freshwater resources. With reduced irrigation needs, farmers can save on production costs and cut down on the energy used for irrigation systems. Plus, hydrogels can work hand-in-hand with controlled-release fertilizers and precision irrigation technologies, making agriculture more sustainable overall (Venkatachalam & Pushparaju, 2022). However, there are still some hurdles to overcome before hydrogel technology can be widely adopted. For instance, synthetic hydrogels can linger in the soil for a long time, potentially leading to environmental pollution. On top of that, the high production costs can make it tough for smallholder farmers to access these technologies (Adjuik et al., 2022). That's why current research is focused on creating low-cost, biodegradable hydrogels made from renewable materials to support sustainable farming practices.

Conclusion

Hydrogel technology is an exciting solution for managing soil water sustainably, especially in arid and semi-arid areas that are grappling with climate change and dwindling water supplies. By boosting soil's ability to hold moisture, enhancing how efficiently water is used, and helping crops thrive even during droughts, hydrogels play a crucial role in creating farming systems that can withstand climate challenges. When combined with climate-smart agricultural practices, they can lower irrigation needs, improve soil health, and bolster food security in at-risk regions. While there are still hurdles to overcome, such as costs, accessibility, and potential long-term environmental impacts, ongoing research, technological progress, and educational initiatives for farmers can pave the way for broader use of hydrogel technology in sustainable agriculture.

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KHET BACHAO ABHIYAN: SAVING OUR FIELDS THROUGH BALANCED AND INTEGRATED NUTRIENT MANAGEMENT

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India's Green Revolution demonstrated the value of mineral fertilisers in raising crop yields and strengthening food security. Over time, however, repeated or imbalanced application - particularly excessive reliance on nitrogen without adequate phosphorus, potassium, secondary nutrients, micronutrients, or organic matter - has contributed to declining nutrient-use efficiency, rising cultivation costs, soil degradation, and nutrient losses to water and the atmosphere. The Khet Bachao Abhiyan responds to this challenge by promoting balanced and judicious fertiliser use rather than an abrupt withdrawal of mineral fertilisers (Food and Agriculture Organization of the United Nations [FAO], 2019; Indian Council of Agricultural Research [ICAR], 2026).

The campaign's central proposition is that fertiliser should be treated as one element within a wider nutrient-management system. Farmyard manure, compost, vermicompost, crop residues, green manures, biofertilisers, and carefully evaluated nutrient-rich by-products can complement mineral sources. When these inputs are selected according to soil condition, crop demand, climate, and local availability, they can maintain productivity while rebuilding soil organic matter and biological activity (Roy et al., 2006).

This article presents the scientific background and a practical implementation methodology for the campaign. Its aim is to help farmers, extension personnel, and local institutions reduce avoidable chemical dependence without compromising yield or income. The approach is therefore gradual, evidence-based, site-specific, and centred on soil health.

Background

Nutrient balance and crop performance: Healthy crop growth requires macronutrients such as nitrogen (N), phosphorus (P), and potassium (K), together with secondary nutrients and micronutrients including sulphur, zinc, iron, and boron. These nutrients must be available in suitable proportions and at the growth stages when crops need them. Excess nitrogen may produce lush vegetative growth, but can also increase lodging, pest and disease susceptibility, nitrate leaching, and gaseous nitrogen losses. At the same time, insufficient P, K, sulphur, or micronutrients constrains yield and reduces the efficiency of applied nitrogen (Roy et al., 2006).

Balanced fertilisation therefore means more than applying a standard N-P-K dose. It requires matching nutrient sources and rates to soil-test results, crop removal, expected yield, previous crop effects, irrigation regime, and the nutrients returned through residues and manures. Blanket recommendations are especially unsuitable across contrasting Indian soils. Many alluvial and Vertisol fields may contain substantial native K reserves, whereas red and lateritic soils can be acidic, strongly P-fixing, and more vulnerable to K depletion.

Soil, water, and health consequences of misuse: Long-term nutrient imbalance and low organic-matter return can weaken soil aggregation, alter pH, reduce infiltration, and diminish the habitat and food supply of beneficial soil organisms. These changes can make fields more compact, erosion-prone, and less resilient to drought or intense rainfall. Excess nutrients that leave the root zone are also an economic loss: nitrate can contaminate groundwater, while nitrogen and phosphorus entering surface waters can stimulate eutrophication. High nitrate exposure in drinking water is a recognised health concern, particularly because of the risk of infant methaemoglobinaemia (World Health Organization, 2016).

The objective is not to replace one input dependency with another. Organic materials vary in nutrient content and release rate, and microbial inoculants require viable formulations, correct storage, and suitable soil conditions. Similarly, industrial by-products may contain useful nutrients but can also introduce salts, trace metals, or other contaminants. Sustainable nutrient management therefore combines agronomic benefit with quality control and risk assessment.

Integrated nutrient management as the campaign foundation: Integrated nutrient management (INM) combines mineral, organic, and biological nutrient sources in a coordinated plan. Mineral fertilisers supply concentrated and predictable nutrients; manures and composts contribute organic carbon and a broader nutrient spectrum; residues and green manures recycle nutrients within the farm; and biofertilisers improve biological nitrogen fixation or mobilise nutrients already present in soil. The proportions should change with the field, crop, season, and resources rather than follow a universal substitution target (Roy et al., 2006).

This principle is consistent with the Khet Bachao Abhiyan's emphasis on Soil Health Cards, balanced fertiliser use, organic inputs, vermicomposting, and biofertilisers (ICAR, 2026). The campaign should therefore be understood as a productivity-and-soil-health programme: it seeks smarter nutrient use, not simply lower fertiliser consumption.

Methodology

Review and synthesis approach

This article is a narrative, practice-oriented technical synthesis; it does not report a new field experiment. The original extension content was reorganised around five evidence domains: balanced plant nutrition, soil and water protection, biological nutrient processes, recycling of farm resources, and field-level decision support. The discussion was aligned with international guidance on integrated plant nutrition and responsible fertiliser management, peer-reviewed literature on biofertilisers and green manures, and current ICAR extension messaging.

Recommendations were screened against four practical criteria: (i) compatibility with soil and crop conditions; (ii) potential to maintain yield while improving nutrient-use efficiency; (iii) feasibility for farmers in terms of cost, labour, and local availability; and (iv) safeguards against contamination or inappropriate substitution. Because this is not a systematic review or meta-analysis, it does not assign universal savings percentages or fertiliser doses. Rates and products must be selected through locally validated recommendations, label directions, and soil-test interpretation.

Field implementation framework

Step 1: Diagnose the field before prescribing inputs

The process begins with representative soil sampling and interpretation of pH, organic carbon, available N, P, K, sulphur, and relevant micronutrients. The diagnosis should also record crop sequence, yield history, residue management, irrigation, drainage, erosion risk, and locally available manures or biomasses. These observations distinguish an actual nutrient deficiency from a constraint caused by acidity, salinity, water stress, compaction, or poor rooting.

Step 2: Construct a balanced nutrient basket

The nutrient plan should combine the minimum effective mineral fertiliser requirement with dependable organic and biological sources. In acidic red and lateritic soils, locally suitable low-grade rock phosphate may provide P gradually, particularly when used with compost, green manures, or other acidifying biological processes. Phosphorus-enriched compost or vermicompost can be prepared by incorporating approved P sources into organic material under a controlled composting process. Such options must be compared with soluble fertilisers on the basis of soil pH, crop duration, and expected response.

Crop demand should guide fertiliser choice. Single superphosphate supplies both P and sulphur and can be useful for pulses and oilseeds where sulphur contributes to protein and oil synthesis. Slow-release P sources may suit longer-duration fruit or plantation systems when soil conditions support their dissolution. Highly soluble diammonium phosphate should not be used merely by habit when a different source better matches the soil and crop.

Step 3: Mobilise nutrients through biological processes

Biofertilisers can complement fertilisers when strains, carriers, storage, and application methods are appropriate. Rhizobium in compatible legumes, Azotobacter, Azospirillum, cyanobacteria, and other plant-growth-promoting microorganisms can support biological N inputs or improve nutrient acquisition. Phosphate-solubilising microorganisms, including selected Bacillus, Pseudomonas, Aspergillus, and Penicillium strains, release organic acids or enzymes that increase the availability of sparingly soluble P; other microorganisms can contribute to K mobilisation. These benefits are strongly influenced by soil and environmental conditions, so inoculants should be quality-assured and demonstrated locally (Khan et al., 2007; Sharma et al., 2013; Vessey, 2003).

Step 4: Build organic matter and recycle farm nutrients

Leguminous green manures such as Sesbania, sunhemp, and cowpea can add biologically fixed N and fresh organic matter to rice-based systems. Green leaf manure from suitable trees, including Gliricidia, Pongamia, and neem, can further supplement nutrients where biomass is safely available. The amount of mineral N that can be replaced varies with biomass production, incorporation time, water regime, and synchrony between decomposition and crop demand; labour and land availability also affect adoption (Becker et al., 1995).

Crop residues, weeds, animal dung, and other farm biomasses should be recycled through well-managed composting or vermicomposting rather than burned or discarded. Mature compost returns carbon and nutrients to the field, while vermicompost can provide biologically active material that supports root growth and nutrient cycling. Feedstock quality, moisture, aeration, decomposition stage, and freedom from contaminants determine the value of the final product.

Step 5: Diversify cropping systems

Cereal-legume rotations and intercropping use rooting patterns, seasonal niches, and biological N fixation more effectively than continuous cereal cultivation. Legumes can reduce the N requirement of the system, while diverse roots capture water and nutrients from different soil layers. The fertiliser plan for the following crop should credit the preceding legume and retained residues instead of treating every season as independent.

Step 6: Improve placement, timing, and delivery

Efficient application is as important as the nutrient source. Because P moves slowly in most soils, placement near the active root zone generally improves access. In puddled rice, basal incorporation and, where feasible, deep placement of urea supergranules can reduce avoidable N losses. Splitting N and K into smaller doses aligned with crop demand is especially useful in sandy, lateritic, or high-rainfall situations where leaching risk is greater. Labour availability, moisture, and farm machinery must be considered when choosing a placement method.

Foliar nutrition can correct a diagnosed in-season deficiency or supplement soil application when root uptake is restricted by drought, salinity, or other adverse conditions. Emerging products such as nano-DAP may improve P-use efficiency in specific crop and application combinations, but results are product-, dose-, crop-, and environment-specific. Recent field evidence in wheat is promising, yet it also supports the need for locally validated protocols rather than blanket replacement claims (Reddy et al., 2025).

Step 7: Evaluate alternative by-products with safeguards

Fly ash, wood ash, rice-husk ash, press mud, and related by-products can contain K, calcium, magnesium, sulphur, silicon, or other useful elements. Their agricultural use should be considered only after laboratory characterisation of pH, salinity, nutrient content, and potentially toxic elements. Source traceability, crop suitability, permitted application rates, and long-term soil monitoring are essential. Fly ash, for example, may improve selected soil properties at low, appropriate rates, but excessive application can suppress microbial activity and increase heavy-metal risk (Pandey & Singh, 2010).

Step 8: Select responsive varieties and monitor outcomes

Varieties that sustain acceptable yield under moderate nutrient supply can improve net returns when the real cost of fertiliser is considered. Each field plan should be evaluated using crop yield, fertiliser cost, labour, visible deficiency symptoms, soil-test trends, organic carbon, and any relevant environmental indicators. Farmer-managed comparison strips can show whether a reduced or rebalanced dose performs as intended before the practice is expanded.

Extension and artificial intelligence support

Location-specific advice is essential because soil type, rainfall, irrigation, cropping pattern, labour, and organic-resource availability vary sharply among villages and farms. Extension programmes should combine soil-test interpretation, field demonstrations, farmer feedback, and training on composting, inoculant handling, and safe by-product use. Demonstrations should compare yield, cost, and soil-health outcomes so that farmers can see that INM means more efficient production rather than forced yield reduction.

Artificial-intelligence decision tools can strengthen, but should not replace, local agronomic judgement. A useful system would integrate soil-test data, crop stage, expected yield, weather forecasts, irrigation, local input availability, and previous field performance. Its recommendations should be explainable, linked to approved agronomic guidance, and reviewed by extension specialists. Feedback from farmers can then refine subsequent recommendations and turn each participating field into a monitored learning site.

Conclusion

The Khet Bachao Abhiyan offers a practical pathway for protecting soil while safeguarding farm productivity. Its message is not that all mineral fertilisers are harmful, but that inefficient and imbalanced use imposes avoidable costs on farmers, soils, water, and society. The most durable response is balanced, soil-test-based fertilisation integrated with organic matter recycling, biological inputs, crop diversification, and better timing and placement.

Implementation should proceed field by field. Reliable diagnosis, quality inputs, locally validated rates, farmer demonstrations, and monitoring are necessary to convert broad principles into economic gains. Biofertilisers, green manures, composts, nano-fertilisers, and industrial by-products each have potential, but none is a universal substitute. Their value depends on matching the intervention to the soil-crop system and managing associated risks.

By combining scientific evidence with farmers' experience, the campaign can improve soil biological activity, nutrient-use efficiency, resilience, and net returns. Protecting the field ultimately protects the farmer: healthy soils support stable harvests, cleaner environments, and more secure rural livelihoods.

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MARINE WORMS: THE SECRET BEHIND HEALTHY SHRIMP BROODSTOCK

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Successful shrimp farming begins with healthy broodstock capable of producing large numbers of high-quality eggs and larvae. Broodstock shrimp require nutrient-rich diets to mature, spawn regularly and produce robust offspring. Although formulated broodstock feeds are available, most shrimp hatcheries continue to use natural feeds such as squid, mussels, clams and polychaete worms.

Among these feeds, polychaetes are particularly important because they contain high-quality protein, essential fatty acids, phospholipids, cholesterol, vitamins and minerals. Consequently, they are widely regarded as one of the most effective natural maturation feeds for penaeid shrimp (Chimsung, 2014).

What Are Polychaetes?

Polychaetes are segmented marine worms belonging to the phylum Annelida. The name "polychaete" means "many bristles," referring to the numerous hair-like chaetae present on their body segments. These bristles help the worms crawl, swim, burrow or anchor themselves in marine sediments. Polychaetes occur in almost every marine environment, including estuaries, mangroves, sandy beaches, mudflats, seagrass beds and the deep sea. Depending on the species, they feed on algae, microorganisms, detritus, organic matter or small animals. Several polychaete genera are used as shrimp broodstock feed, including *Perinereis*, *Nereis*, *Marphysa*, *Hediste*, *Alitta* and *Glycera*. In India, species belonging to *Marphysa* and *Perinereis* are commonly collected from coastal areas and supplied to shrimp hatcheries.

Why Do Shrimp Breeders Feed Polychaetes?

Reproduction is an energy-intensive process. Female shrimp require substantial quantities of nutrients to develop their ovaries and produce eggs, while males need balanced nutrition for the formation of sperm and spermatophores. Nutritional deficiencies can delay gonadal maturation, reduce spawning frequency and adversely affect egg and larval quality.

Polychaetes provide reproductive nutrients in a natural and readily digestible form. Their soft body tissues are easily consumed by shrimp, while their natural smell and movement stimulate feeding. Live worms may encourage broodstock to feed even when they show a poor response to formulated diets. In hatcheries, polychaetes are normally offered as part of a mixed maturation diet containing squid, mussel, clam and formulated feed. Such a combination provides a broader range of nutrients than any single feed ingredient (Chimsung, 2014).

Nutritional Value of Polychaetes

High-quality protein

Polychaetes are rich in protein and essential amino acids required for maintaining broodstock tissues and developing reproductive organs. In female shrimp, amino acids support the synthesis of vitellogenin, an egg-yolk precursor deposited in developing oocytes.

However, nutritional composition differs considerably among polychaete species. Li et al. (2025) compared three species and found that *Marphysa maxidenticulata*, which contained favourable levels of protein and polyunsaturated fatty acids, produced better growth and reproductive responses in female Pacific white shrimp, *Penaeus vannamei*. Therefore, selecting the right polychaete species is important.

Essential fatty acids

One of the most valuable features of polychaetes is their content of long-chain polyunsaturated fatty acids, particularly:

- Arachidonic acid (ARA)
- Eicosapentaenoic acid (EPA)
- Docosahexaenoic acid (DHA)

These fatty acids are involved in cell membrane formation, ovarian maturation, embryonic development and larval growth. ARA is also a precursor of hormone-like compounds called eicosanoids, which participate in several reproductive processes. Dietary ARA has been shown to improve the reproductive performance of *P. vannamei* broodstock (Xu et al., 2017). EPA and DHA contribute to the development of eggs and embryos and provide energy to newly hatched larvae. The balance among ARA, EPA and DHA is therefore more important than simply providing a high level of dietary lipid.

Cholesterol and phospholipids

Shrimps have a limited ability to synthesise cholesterol and must obtain it through their diet. Cholesterol is required for cell membranes and for producing moulting and reproductive hormones. Phospholipids help shrimp digest, transport and utilise dietary lipids. They are also major structural components of egg and embryonic cell membranes. Together, cholesterol and phospholipids support ovarian maturation, egg formation and embryonic survival.

Vitamins and minerals

Polychaetes contain vitamins and minerals involved in metabolism, antioxidant defence and reproduction. Some species may also provide carotenoids and other biologically active substances. Extracts from marine polychaetes have been reported to stimulate reproductive processes in penaeid shrimp, although the active compounds and their precise mechanisms are not yet fully understood (Nguyen et al., 2012).

Reproductive Benefits

Faster ovarian maturation and spawning

The protein, fatty acids, cholesterol and phospholipids supplied by polychaetes support vitellogenesis and oocyte development. Females receiving nutritionally suitable worms may therefore attain advanced stages of ovarian maturation more efficiently. Li et al. (2025) observed that female *P. vannamei* fed *M. maxidenticulata* had greater ovarian accumulation of triglycerides, estradiol and vitellogenin, as well as larger mature oocytes, than shrimp fed the other polychaetes tested.

Well-nourished females are more likely to spawn consistently and recover between spawning events. Nevertheless, reproduction is also influenced by broodstock age, genetics, health, water quality, stocking density and hatchery management. Polychaetes should therefore be considered part of a comprehensive broodstock programme rather than a stand-alone solution.

Improved egg and larval quality

Nutrients obtained from the maternal diet are transferred to developing eggs. Eggs containing an appropriate balance of amino acids, fatty acids and phospholipids are more likely to undergo normal embryonic development and produce healthy nauplii. The benefits of polychaete feeding can therefore extend to fertilisation, hatching, larval activity and stress tolerance. Hatcheries should assess not only the number of nauplii produced but also their uniformity, activity, survival and subsequent developmental performance.

Benefits to male broodstock

Male shrimp also benefit from polychaete supplementation. Protein and essential fatty acids support the development of testes, sperm and spermatophores. Polychaete feeding has been associated with improved sperm performance and reproductive condition in male black tiger shrimp, *P. monodon* (Leelatanawit et al., 2014).

Biosecurity Concerns

Despite their nutritional benefits, wild polychaetes may present serious biosecurity risks. Worms collected near shrimp farms or from contaminated sediments can carry shrimp pathogens, including white spot syndrome virus, *Enterocytozoon hepatopenaei* (EHP) and bacteria associated with acute hepatopancreatic necrosis disease (Desrina et al., 2018). A study conducted in India detected EHP and WSSV in wild polychaetes. Experimental evidence also demonstrated that EHP-contaminated worms could transmit the pathogen to healthy shrimp. The researchers concluded that feeding wild-caught polychaetes could increase the risk of introducing EHP into shrimp hatcheries (Krishnan et al., 2021).

Freezing cannot automatically be assumed to eliminate every pathogen. Hatcheries should obtain worms from traceable sources and follow appropriate screening, processing, storage and hygiene procedures. PCR-based screening for major shrimp pathogens is particularly important for worms intended for specific-pathogen-free broodstock.

Conclusion

Polychaetes are far more than ordinary marine worms. They are natural packages of protein, essential fatty acids, cholesterol, phospholipids, vitamins and minerals needed for shrimp reproduction. When included in a balanced maturation diet, they can support ovarian development, spawning, egg quality, hatchability, sperm performance and larval quality.

However, dependence on wild worms raises concerns regarding pathogen transmission, inconsistent supply and environmental damage. The future lies in the controlled, biosecure and sustainable farming of nutritionally enriched polychaetes.

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THE ROLE OF EXTENSION PERSONNEL IN REMOTE SENSING-BASED INFORMATION AND CROP INSURANCE IN EMERGING ECONOMIES

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Agriculture in emerging economies is increasingly exposed to climate variability, extreme weather events, pest outbreaks, and production uncertainties, making effective risk management essential for ensuring farmers' livelihoods. Remote sensing technology has emerged as a transformative tool by providing timely, accurate, and cost-effective information on crop conditions, acreage, vegetation health, soil moisture and disaster impacts through satellite and unmanned aerial vehicle (UAV) imagery. These advancements have significantly improved crop insurance programmes by enabling faster damage assessment, yield estimation, and transparent claim settlement. However, the successful implementation of remote sensing-based crop insurance depends not only on technological innovations but also on the effective dissemination and interpretation of information at the grassroots level. Agricultural extension personnel play a pivotal role in bridging the gap between advanced geospatial technologies and farming communities. They create awareness about insurance schemes, facilitate farmer enrolment, interpret satellite-based advisories, validate field conditions through ground-truthing, assist in claim documentation, enhance farmers' digital literacy and provide continuous feedback to research institutions and insurance agencies. Their involvement strengthens farmers' trust in technology-driven insurance systems while promoting informed decision-making and climate-resilient agricultural practices. Despite considerable progress, several challenges remain, including inadequate digital infrastructure, shortage of trained extension personnel, limited technical capacity, connectivity issues and basis risk associated with satellite-based assessments. Strengthening extension systems through regular capacity building, digital skill enhancement, institutional coordination and integration with remote sensing platforms is essential for improving the efficiency, transparency and inclusiveness of crop insurance programmes. A strong partnership between extension services, remote sensing technologies, and insurance institutions can significantly enhance agricultural resilience, reduce production risks, and support sustainable rural development across emerging economies. This integrated approach will contribute to climate-smart agriculture and long-term food security. The article emphasizes the indispensable role of extension personnel in achieving these outcomes.

Agriculture in emerging economies remains heavily exposed to weather variability, pest outbreaks, and climate shocks, and smallholder farmers who make up the majority of producers in South Asia, Sub-Saharan Africa, and parts of Southeast Asia and Latin America carry a disproportionate share of this risk. Crop insurance has emerged as a central instrument for stabilizing farm incomes, but conventional loss-assessment methods built on manual crop-cutting experiments and field visits are slow, costly, and prone to dispute. Advances in satellite and unmanned aerial vehicle (UAV) remote sensing now allow yield and damage estimates to be generated at a fraction of the cost and time, and are increasingly embedded in national insurance programs across the developing world.

Yet technology alone does not reach the farmer. Agricultural extension personnel, the frontline officers who interpret science for practice, remain the critical link that converts satellite-derived indices and portal-based claims data into decisions farmers can act on: when to enrol, how to interpret an alert, and how to pursue a claim. This report examines the concept of remote sensing in agriculture, the state of crop insurance in emerging economies, and the specific roles extension personnel play in making remote sensing-based insurance systems functional, equitable, and trusted at the village level.

Concept of Remote Sensing

Remote sensing refers to the acquisition of information about the Earth's surface without physical contact, typically through sensors mounted on satellites, aircraft, or UAVs. In agriculture, optical sensors capture reflectance in visible and near-infrared bands to compute vegetation indices such as the Normalized Difference Vegetation Index (NDVI), which correlates with crop vigor and biomass, while synthetic aperture radar (SAR) penetrates cloud cover to detect soil moisture, flooding, and crop structure regardless of weather. These data streams are combined with weather station records, soil information, and, increasingly, machine-learning models to estimate crop area, monitor phenological stages, detect stress, and forecast yield at scales ranging from a single field to an entire district.

Two features of remote sensing make it especially relevant to insurance in emerging economies. First, coverage: a single satellite pass can observe thousands of villages simultaneously, something manual field sampling cannot match. Second, the pace of infrastructure growth has been rapid; commercial Earth observation constellations have expanded from a handful of new satellites launched annually earlier in the decade to well over a hundred per year by the mid-2020s, improving the frequency and resolution of imagery available for agricultural monitoring.

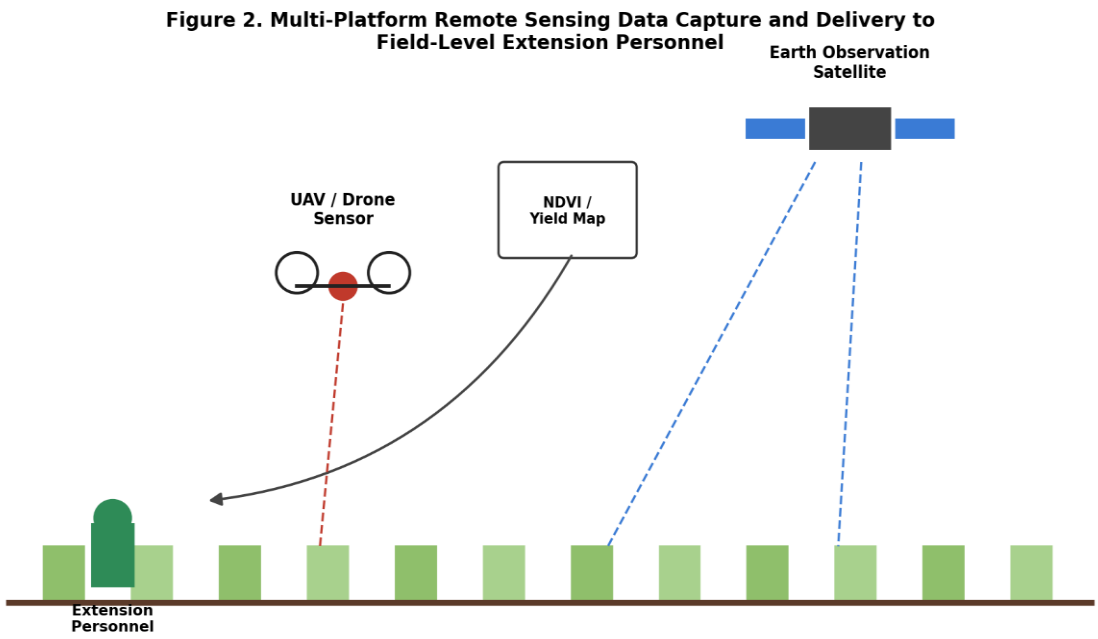

Fig. 2: Multi-platform remote sensing data capture (satellite and UAV) and its delivery pathway to field-level extension personnel who translate raw imagery into farmer-facing advisories.

Crop Insurance in Emerging Economies

Comparable index-insurance and remote-sensing-linked products have grown in Sub-Saharan Africa and parts of Latin America and Southeast Asia, often supported by development partners, though most remain smaller in scale than India's program and continue to face challenges around basis risk, the gap between an index's estimate of loss and a farmer's actual loss on the ground. A systematic review of the literature on satellite-based agricultural index insurance underscores that while remote sensing lowers the cost of loss verification, its accuracy is highly dependent on local crop classification, ground validation, and the institutional capacity that surrounds the technology.

Common Program Features

Table 1: Common structural features of remote sensing-linked crop insurance programs in emerging economies.

Feature	Description
Area-yield basis	Claims are triggered by shortfalls against a threshold yield computed for a defined insurance unit rather than an individual farm.
Technology blending	Satellite/UAV-derived yield estimates are combined with traditional Crop Cutting Experiments (CCEs) rather than fully replacing them.
Subsidized premiums	Government contributions keep farmer-paid premiums low, typically a small fixed percentage of the sum insured.
Digital portals	Centralized platforms (e.g., National Crop Insurance Portal in India) integrate enrolment, land records, weather data, and claims processing.
Extension-mediated enrolment	Field officers and bank/cooperative intermediaries remain the main channel through which smallholders learn about and join schemes.

Role of Agricultural Extension Personnel

Extension personnel occupy the interface between the technical apparatus of remote sensing-based insurance and the lived reality of smallholder decision-making. Evidence from climate-smart agriculture research consistently finds that the quality and trust associated with face-to-face advisory contact, not mere access to information, is what drives farmer awareness and adoption of new practices and products. Their contributions can be grouped into the following functions.

Table 2: Core functions performed by agricultural extension personnel within remote sensing-based crop insurance systems.

Function	Extension Personnel Contribution
Awareness creation and enrolment	Explaining scheme rules, insurance units, cut-off dates, and how satellite-based yield estimation affects claim calculation, in local language and through farmer group meetings.
Interpretation of technical outputs	Translating NDVI maps, weather alerts, and modelled yield figures from portals such as WINDS or YES-TECH dashboards into actionable guidance farmers can use for sowing, irrigation, or claim decisions.
Ground-truthing and data quality support	Assisting with Crop Cutting Experiments, verifying crop-type maps against actual field conditions, and flagging discrepancies between satellite estimates and observed losses.
Grievance redressal and claims facilitation	Helping farmers document losses, understand claim rejections, and navigate the appeals process when remote sensing-based assessments are disputed.

Capacity building and digital literacy	Training farmers and para-extension workers (e.g., Krishi Sakhis, lead farmers) to use mobile apps and SMS-based advisories linked to insurance and weather platforms.
Feedback to technical agencies	Relaying field-level observations back to modelling agencies (e.g., MNCFC, ISRO-linked institutions, national meteorological services) to improve model calibration.

Practical Applications Applications

I. Pre-season advisories combining satellite soil-moisture data with extension-led guidance on sowing windows and crop choice.

II. In-season stress alerts (drought, waterlogging, pest-favorable conditions) pushed via SMS or mobile apps, with extension officers following up in person for high-risk cases.

III. Post-harvest yield reconciliation, where extension staff support validation of modelled yield against sample harvests to reduce disputes at claim settlement.

IV. Farmer field schools and demonstration plots that build trust in remote sensing-derived recommendations before scaling to insurance-linked decisions.

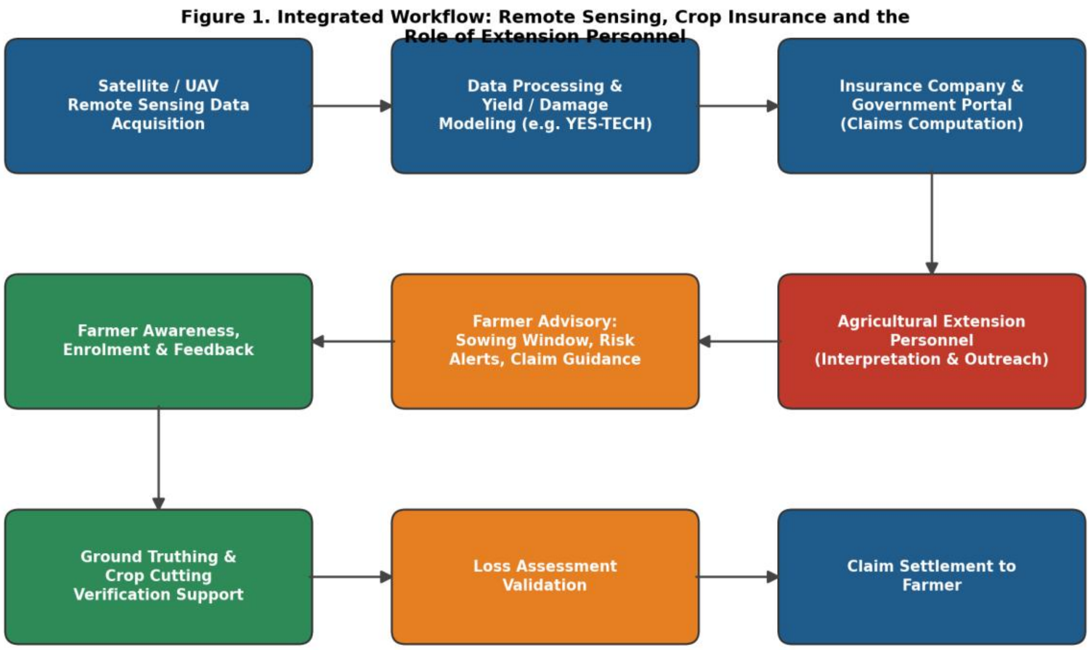

Fig 1: Integrated workflow linking remote sensing data acquisition, technology-based yield modelling, and the mediating role of extension personnel through to claim settlement.

Case Studies

India: PMFBY, YES-TECH and WINDS

India's PMFBY has piloted and scaled the Yield Estimation System based on Technology (YES-TECH) since 2023, mandating a minimum weightage for technology-derived yield in claim calculations for paddy and wheat, with reported implementation across pilot districts without major disputes in the initial Kharif 2023 rollout. A complementary Weather Information Network and Data Systems (WINDS) initiative is establishing hyper-local automatic weather stations to strengthen the data layer feeding these models. District and block-level extension officers, along with Common Service Centres and bank correspondents, remain the primary channel through which farmers understand and access these digital layers, and government guidelines explicitly assign States responsibility for adopting satellite and UAV remote sensing for crop area estimation, yield disputes, and loss assessment.

The Government of India, in partnership with development agencies, has also worked to widen access to credit and insurance for small, marginal, and women farmers, an effort that depends substantially on the last-mile trust that extension networks provide, since digital yield dashboards alone do not resolve farmer skepticism about automated claim decisions.

Sub-Saharan Africa: Index Insurance and Advisory Ecosystems

In Malawi, satellite-based damage mapping supported rapid post-disaster assessment following Cyclone Freddy in 2023, illustrating remote sensing's value for both routine index insurance and emergency response. More broadly, research across Ghana, Nigeria, Kenya, and South Africa finds that public extension agents remain the most frequently used advisory channel for smallholders, ahead of mobile platforms, though effectiveness depends heavily on advisors' own training in climate and remote-sensing-derived information; studies in South Africa's Limpopo province, for instance, found that a majority of extension practitioners lacked formal training in climate-change-related advisory content, constraining their ability to translate remote sensing outputs into farmer guidance.

Cross-Cutting Observations

- Programs that pair remote sensing infrastructure with a well-resourced extension cadre report fewer claim disputes and faster settlement.

- Where extension capacity is thin or undertrained in digital tools, farmers report low awareness of adaptation and insurance options even when technical infrastructure exists.
- Hybrid information ecosystems, extension agents working alongside farmer groups, mobile applications, and radio, tend to outperform any single channel used alone.

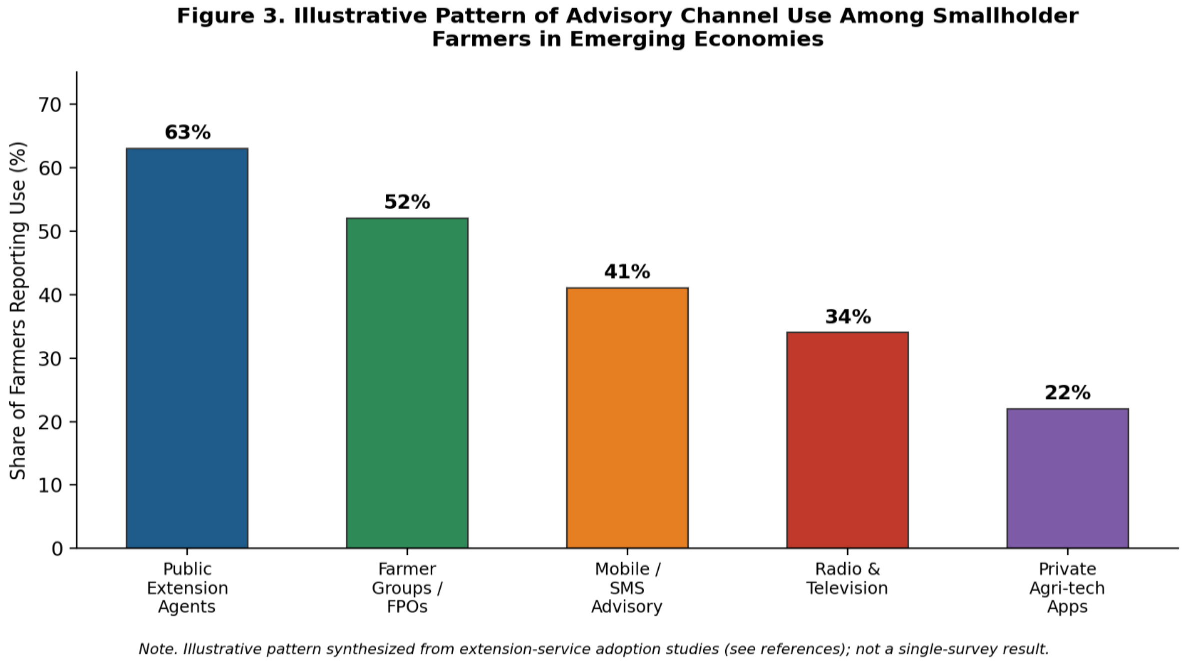

Fig. 3: Illustrative pattern of advisory channel use among smallholder farmers, synthesized from extension-adoption studies cited in this report; figures are indicative rather than drawn from a single survey.

Challenges

Table 3: Principal challenges constraining the extension-mediated delivery of remote sensing-based crop insurance.

Challenge	Description
Extension staff shortages	Low extension officer-to-farmer ratios in many emerging economies limit the frequency and depth of in-person contact needed to build trust in remote sensing-derived decisions.
Digital and technical skill gaps	Many field officers have not received formal training in interpreting satellite indices, weather-model outputs, or insurance dashboards.
Basis risk and farmer distrust	Discrepancies between modelled yield/damage estimates and a farmer's actual field experience can undermine confidence in both the technology and the extension officers who communicate it.
Infrastructure and connectivity	Poor rural internet and mobile connectivity constrain the delivery of real-time alerts and dashboard access in remote areas.

Institutional coordination	Fragmented responsibilities among meteorological agencies, insurance companies, technology implementation partners, and extension departments slow feedback loops.
Language and last-mile translation	Technical outputs must be reformulated in local languages and farmer-relevant terms, a task that is resource- and skill-intensive at scale.

Future Prospects

The rapid expansion of commercial Earth observation constellations is expected to further increase the spatial and temporal resolution of agricultural monitoring available to insurance programs, while artificial intelligence and machine-learning-based yield models continue to mature. Realizing the benefit of these advances for smallholders will depend on parallel investment in extension capacity: structured training curricula on remote sensing interpretation, digital advisory tools tailored for low-bandwidth settings, and stronger integration of extension feedback into model calibration. Emerging approaches such as delinking insurance subsidy disbursement from state government timelines, expanding hyper-local weather networks, and building para-extension cadres (for example, community-based lead farmers and women's agricultural collectives) point toward more resilient, farmer-trusted systems in the years ahead.

Conclusion

Remote sensing has fundamentally changed what is technically possible in agricultural insurance, allowing yield and damage estimates to be generated faster, more objectively, and at a scale manual methods cannot match. But technology alone cannot deliver trust, comprehension, or equitable access. Agricultural extension personnel remain the indispensable human infrastructure that converts satellite data into decisions farmers can act on, mediates disputes, and channels field-level realities back into technical systems. Strengthening extension capacity, training, staffing, and digital tools, should therefore be treated as a core investment alongside satellite infrastructure itself if remote sensing-based crop insurance is to fulfil its promise for smallholders across emerging economies.

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