Food and Agriculture Organization of the United Nations

4th International Conference on

Climate-Smart Agriculture

CSA-2026

ABSTRACT BOOK



20–21 October 2026

Muhammad Nawaz Shareef University of Agriculture Multan, Pakistan

ORGANIZED BY
Department of Agronomy, MNSUAM

IN COLLABORATION WITH
FAO Pakistan · Punjab Higher Education Commission

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CLIMATE-SMART AGRICULTURE: The Way Towards Sustainable Food Security

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About CSA-2026

The 4th International Conference on Climate-Smart Agriculture (CSA-2026) is being held on 20–21 October 2026 at Muhammad Nawaz Shareef University of Agriculture, Multan, Pakistan. The conference focuses on advancing climate-resilient, resource-efficient and sustainable agricultural systems to ensure food security under changing climatic conditions.

The event will feature keynote lectures, invited talks, technical sessions, a panel discussion on World Food Day 2026 and opportunities for research networking. It will connect national and international expertise from universities, research institutes, FAO Pakistan, government departments, private-sector organizations and development partners.

Conference Objectives

- To share recent research on climate change impacts, adaptation, and mitigation in agriculture.
- To promote climate-smart, water-efficient, and regenerative agricultural practices.
- To highlight precision agriculture, crop modeling, remote sensing, and digital innovations.
- To strengthen sustainable nutrient management and integrated pest and weed management.
- To encourage policy dialogue for resilient agrifood systems and sustainable food security.
- To build partnerships among academia, research institutions, farmers, industry, and development organizations.

Conference Themes

1	Water Resource Management and Water-Efficient Agriculture
2	Climate Change and Climate-Smart Agriculture Practices
3	Crop Modeling, Precision Agriculture and Digital Technologies
4	Regenerative and Integrated Agriculture
5	Sustainable Nutrient Management and Smart Plant Protection
6	Food Policy and Sustainable Agrifood Systems

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1. From Climate Risk to Resilient Harvests: Modeling Pathways for Climate-Smart Agriculture

Ashfaq Ahmad

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Abstract: Climate change is rapidly reshaping agricultural production through rising temperatures, changing rainfall patterns, increasing frequency of droughts and floods, heat stress, and growing uncertainty in water availability. These challenges pose serious threats to crop productivity, food security, and rural livelihoods, particularly in climate-vulnerable regions such as Pakistan and South Asia. Building resilient agricultural systems therefore requires a shift from reactive management toward science-based, predictive, and climate-smart decision-making. Crop and climate simulation models provide powerful tools for understanding how changing climatic conditions influence crop growth, development, yield, water productivity, and resource use. By integrating field experiments with historical weather data, future climate projections, soil information, and crop management practices, modeling approaches can quantify climate risks and explore potential adaptation pathways before they are implemented at large scales. Models such as DSSAT and APSIM, together with integrated assessment frameworks including the Agricultural Model Intercomparison and Improvement Project (AgMIP), offer valuable opportunities to evaluate the vulnerability and resilience of cropping systems under changing climates. Major agricultural systems in Pakistan and South Asia, including wheat-, rice-, maize-, and cotton-based production systems, are increasingly exposed to temperature stress, rainfall variability, water scarcity, and extreme weather events. Climate-smart adaptation strategies such as the development and selection of resilient cultivars, adjustment of planting dates, improved irrigation management, efficient nutrient use, conservation practices, precision agriculture, and improved crop management can reduce these risks while sustaining productivity. The integration of crop modeling with reliable climate information, field observations, digital technologies, and stakeholder knowledge can transform agricultural research into practical decision-support systems. Such approaches can support researchers, farmers, policymakers, and institutions in identifying location-specific adaptation strategies and developing resilient pathways for future food production. Strengthening modeling capacity, improving climate information services, and promoting evidence-based agricultural planning will be essential to transform climate risks into resilient harvests and secure sustainable food systems for future generations.

Keywords: Climate change; Crop resilience; Climate-smart agriculture; Crop simulation modeling; DSSAT; APSIM; AgMIP; Climate adaptation; Food security; Sustainable agriculture.

2. Lithium in Agricultural Food Systems: Assessing Soil Contamination and Risks to Vegetable Production

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Abstract: Lithium (Li) is the lightest monovalent alkali metal and an emerging environmental pollutant due to natural release from parent materials and anthropogenic sources, including brines, Li-containing batteries, automobiles, and biosolids. Although Li has no known role in oxidation–reduction reactions in biological systems, it can interact with polypeptides and proteins. Its increasing presence in the environment warrants assessment of its toxicity and potential transfer through the food chain. However, information on Li levels in soil, water, and food crops remains limited.

A survey of food crops and water showed that legumes had the highest Li accumulation in edible plant parts (325 µg g^{-1} DW), followed by oilseed crops (146.67 µg g^{-1}), leafy vegetables (84.0 µg g^{-1}), root crops (80.00 µg g^{-1}), and cereals (64.01 µg g^{-1}). Drinking and groundwater contained negligible Li, whereas municipal wastewater contained appreciable concentrations (2.40 mg L^{-1}), indicating a potential risk of Li accumulation through wastewater irrigation.

A soil culture experiment evaluated the effects of Li application (0, 20, 40, 60, and 80 mg kg^{-1} soil) on carrot, spinach, and cauliflower. Low Li concentration (20 mg kg^{-1}) improved plant growth, particularly in spinach, whereas higher concentrations negatively affected growth, especially in carrot and cauliflower. Li application also interfered with potassium and calcium uptake and promoted greater Li accumulation in leaves than in flowers and roots.

The findings highlight the potential risk of Li transfer into the food chain and emphasize the need for proper crop management on Li-contaminated soils. Cultivation of leafy vegetables and legumes should be avoided in Li-affected soils, while appropriate root and flower crops may be considered where Li accumulation in edible parts remains low.

Keywords: Lithium environmental contamination, Wastewater, Edible plant parts, Cation antagonism

3. Application of Decision Support system for Agro-Technology Transfer; A Case Study of Punjab, Pakistan

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Abstract: Climate variability, resource constraints, declining yield potential, and increasing production risks pose major challenges to sustainable agricultural development in Punjab, Pakistan. Decision Support Systems (DSS) based on process-based crop simulation models provide an effective approach for evaluating alternative crop management strategies and facilitating the transfer of climate-smart agro-technologies. This study presents a framework for applying the Decision Support System for Agro-technology Transfer (DSSAT) to support agro-technology transfer across diverse agro-ecological environments of Punjab. The approach integrates historical weather, soil, crop, and management information with field observations to evaluate crop responses to alternative production practices. Model calibration and evaluation are performed using experimental and farmer-field data, followed by scenario analysis to assess the effects of sowing dates, irrigation, nutrient management, cultivar selection, and climatic variability on crop growth and productivity. The DSS-based approach enables the identification of location-specific management options and quantification of production risks under contrasting climatic conditions. Previous applications of DSSAT in Punjab have demonstrated its potential for optimizing nutrient management in cotton, assessing climate impacts on crop phenology, and evaluating production systems under changing climatic conditions. The proposed framework can therefore bridge the gap between crop modeling research and practical agricultural extension by translating model outputs into easily understandable, location-specific recommendations for farmers, extension personnel, and policymakers. Integration of DSSAT with climate information, remote sensing, and digital agricultural platforms could further strengthen real-time decision-making and technology dissemination. The study highlights the potential of decision-support approaches to enhance resource-use efficiency, climate resilience, productivity, and food security while supporting sustainable agricultural transformation in Punjab and other climate-vulnerable regions.

Keywords: Decision Support System; DSSAT; agro-technology transfer; climate-smart agriculture; crop modeling; climate variability; Punjab; Pakistan; food security.

4. Foliar-Applied Paclobutrazol Improved the Performance of Heat-Stressed Soybean

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Abstract: Soybean is a significant oilseed crop worldwide though, it is highly sensitivity to temperature variation particularly at the pod-filling stage. Climate change is causing an increase in air temperature which is unfavorable to soybean growth and quality. Understanding the physiological processes due to heat in soybean is essential to implement strategies to improve its stress tolerance. A two-year pot trial was conducted at Students' Farm, Department of Agronomy, University of Agriculture Faisalabad, Pakistan during 2024 and 2025 to investigate the ameliorative effects of paclobutrazol (PBZ) on physiological, biochemical, photosynthetic and yield attributes of soybean under different temperature (H_0 = ambient, H_1 = 2-3°C above ambient, H_2 = 4-5°C above ambient) regimes. The experiment was set in a completely randomized design using split treatment structure. The heat stress was imposed by polythene sheet coverage with different perforations at the blooming stage of soybean. The concentrations of foliar paclobutrazol used were 0 mg L^{-1}, 25 mg L^{-1}, 50 mg L^{-1}, 75 mg L^{-1}, and 100 mg L^{-1}. A significant improvement in physiological, biochemical, and agronomic traits was observed during both years under both levels of heat stress as compared to controlled condition (H_0 = ambient). Malondialdehyde level was increased significantly indicating the presence of oxidative damage, whereas chlorophyll pigments, and yield parameters decreased significantly. Although all doses of foliar paclobutrazol played role in alleviating such negative occurrences. Its application at 50 mg L^{-1}, proved best in increasing the thermotolerance through strengthening of the antioxidant defense system, the integrity of the cell, physiological stability, and yield under both stress levels. Moreover, it was established by principal component analysis (PCA), and heatmap analysis that the paclobutrazol and different temperature regimes have a noteworthy effect on the paired association of agronomic and biochemical characteristics, which disturbs agronomic efficiency.

Keywords: *Glycine max*, growth regulator, superoxide dismutase, PCA, heat-map, protein content

5. Smart Weed Management: Precision Sprayer to Reduce Chemical Use by Targeted Weed Management in Row Crops

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Abstract: Precision sprayers combine advanced hardware with deep machine-learning algorithms to make real-time weed management decisions in crop fields. This presentation summarizes field experiences evaluating precision sprayers for weed control in corn and soybean in the United States. Reducing herbicide use while maintaining effective weed control is a major goal of modern agriculture, and targeted herbicide application offers an opportunity to lower chemical inputs and improve environmental sustainability. Precision sprayers use cameras and sensors to identify weeds as the sprayer moves through the field and apply herbicides only where weeds are detected, instead of spraying the entire field. The objective of this work was to compare spot-spray (SS) technology with conventional blanket herbicide applications for early post-emergence (E-POST) and late post-emergence (L-POST) weed control in corn and soybean. Two commercial precision sprayers were evaluated in separate field studies. Greeneye Technology's sprayer was tested in a corn field near Clay Center, Nebraska, in 2022, and John Deere's precision sprayer was evaluated in a soybean field near Mead, Nebraska, in 2023. Herbicide savings varied greatly between years. In 2022, spot spraying reduced herbicide use by 87–94%, whereas savings were much lower (0–5%) in 2023. These differences were mainly due to weed pressure at the time of application; weed infestations were low in 2022 and high in 2023. Despite differences in herbicide use, corn and soybean yields were similar between spot-spray and broadcast treatments in both years. The results show that precision sprayers can provide weed control comparable to traditional broadcast applications while reducing herbicide use, especially in fields with low weed density and where pre-emergence herbicides are already used. This work highlighted that how dual-tank precision sprayer systems may help manage herbicide antagonism and improve weed control.

Keywords: Precision agriculture, Weed control, Herbicides, Sprayer, Corn, Soybean

6. Assessment of Fertilizer Value and Associated Health Risks from Putrescible Solid Waste as Affected by the Composting Techniques

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Abstract: Reutilization of municipal and livestock waste in agriculture can provide valuable nutrients for plant production, however, it may pose serious health risks for humans when its contaminants, especially the heavy metals, end up in plants through waste-soil-plant continuum. This study aimed to examine the effect of contrasting composting techniques on (i) fertilizer value: vegetable yield, nitrogen (N) mineralization and apparent N recovery (ANR) and (ii) associated health risks: selected heavy metal transfer, daily intake of metal (DIM), and health risk index (HRI) from putrescible municipal solid waste when applied to soil. To explore these objectives, aerobically composted (AC), anaerobically composted (ANC), co-composted (CC) and openly dumped wastes were incorporated into the sandy loam filled pots and grown with carrot and spinach. After soil application, about 51% of the applied organic N was mineralized from ANC material, whereas the respective values in case of OD, CC and AC were 35-36, 24-26, and 22-29%, respectively. Consequently, DM yield and vegetable N uptake from the resultant compost were in the order ANC>OD>CC>AC ($P<0.05$). Moreover, vegetable ANR was the highest from ANC (spinach: 42 and carrot: 51%) followed by OD (32 and 40%), CC (23 and 30%) and AC (21 and 27%) material ($P<0.05$). Interestingly, plant uptake of lead, cadmium, and chromium were lowest from ANC as compared to AC, CC or OD ($P<0.05$), irrespective of the vegetable type. Consequently, DMI and the resultant HRI for all these metals were substantially lower in the former as compared to the latter compost materials. Thus, from viewpoint of sustainable waste re-cycling in agriculture, anaerobic composting of putrescible waste is much better than the traditional aerobic composting and/or open dumping which not only have greater N fertilizer value but also reduces the health risks caused by the long-term accumulation of the heavy metals in plants.

Keywords: Waste reutilization, Composting, Organic farming; Kitchen gardening; Solid waste management, Health risk assessment

7. Plant Growth Regulator Application for the Adaptation of Rice Crop to High Temperatures

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Abstract: Increasing temperature due to global warming has emerged one of the gravest threats to rice production. The present study examined the influence of high temperature and exogenously applied plant growth regulators on pollen fertility, anther dehiscence, pollen germination and metabolites synthesis in pollens of two rice cultivars (IR-64 and Huanghuazhan). Plants were subjected to high day temperature (HDT) (35°C ± 2 from 7:00 am to 7:00 pm for 12 h), high night temperature (HNT) (32°C ± 2 from 7:00 pm to 7:00 am for 12 h), and control temperature (CT) (28°C ± 2 for 24 h a day) in controlled growth chambers. Four different combinations of growth regulators; ascorbic acid (Vc), alpha-tocopherol (Ve), brassinosteroids (Br), methyl jasmonates (MeJA), and triazoles (Tr) were used along with a control. Our results depicted that high temperature severely reduced the pollen fertility, anther dehiscence, pollen retention, germination and metabolites synthesis in pollens of both rice cultivars. Nonetheless, exogenous application of various plant growth regulators assuaged the adverse effects of high temperature and Vc+Ve+MeJA+Br was the best combination than the other treatments for every studied characteristic. The HNT posed more negative effects than the HDT. Variations were also apparent between cultivars and Huanghuazhan performed better than IR-64 under high-temperature stress, with higher pollen fertility, better anther dehiscence, and greater pollen retention and germination rates. The greater tolerance of Huanghuazhan to high temperature was related with the higher synthesis of metabolites in this cultivar.

Keywords: Anther Dehiscence, Fertility, High Temperature, Metabolites, Plant Growth Regulators, Pollen Germination

8. Sugarcane Performance Across Varied Agroecologies of Punjab: Finding Resilient Varieties for a Changing Climate

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Abstract: As the climate grows less predictable, sugarcane growers need varieties that perform well across different environments, not just in one place. We tested ten sugarcane genotypes in zonal trials during 2025-26 at seven locations across the province (Khanpur, Bahawalpur, Rajanpur, Kalur Kot, Kot Addu, Challianwala and Bhalwal). Data was recorded about germination, tillering, cane yield, sugar recovery and sugar yield during the study. Cane yield averaged 121.7 t ha^{-1} in the South and 126.9 t ha^{-1} in the Center, but only 83.2 t ha^{-1} in the North. Sugar yield followed the same pattern (14.70, 14.07 and 9.72 t ha^{-1}), while sugar recovery was highest in the South (12.08%) and lowest in the Center (10.97%). Locations within a zone also varied widely; in the center, mean cane yield ranged from 98.5 t ha^{-1} at Kalur Kot to 155.3 t ha^{-1} at Kot Addu. One genotype, S2016 SL-284, stood out by producing the highest cane and sugar yield at all seven locations, including the North, where conditions were hardest (108.8 t ha^{-1} cane; 12.59 t ha^{-1} sugar). Other genotypes, such as CP 00-1101 and S2016 SL-127, did well mainly in the South, and S2012 SL-426 lagged in the South and North. These results showed that variety performance depends strongly on environment attributes, and that combining zone-specific recommendations with broadly adapted genotypes like S2016 SL-284 offers a practical way to protect sugar production under changing climatic situations.

Keywords: Sugarcane, Agroecology, Crop productivity, SL-284

9. Sustainable Sugarcane Production in Punjab on the Face of Changing Climates

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Abstract: Climate change is threatening the sugarcane production globally and particularly semi-arid regions of the world like Pakistan. The crop growth, development and yield of sugarcane crop are adversely affected through extended droughts, extreme heat, salinity and other biotic parameters like the incidence of new insect pests and weeds. This hampers the rural economy of over one million cane growers by declining cane and sugar yields on one hand and sugar and allied industries on the other. Sustainable options lie in improved production practices like planting sugarcane at wider row spacing in comparison to planting at narrow spacing to improve water-use efficiency. Crop residue management practices like trash mulching instead of burning will not only contribute toward soil health improvement but will also reduce the environmental footprints of the sugarcane production system. Integrated weed management at wider row spacing is easy, environmentally safe and cost-effective in nature. Balanced nutrition based on real-time crop health monitoring can not only improve nutrient-use efficiencies but can also save the ecosystem. Research and development efforts should be focused on site-specific evaluation of local and exotic germplasm for the identification of climate-resilient sugarcane varieties. Locally available sugarcane germplasm should be improved through traditional breeding coupled with novel breeding techniques such as gene editing. Furthermore, the germplasm exchange program should be revamped to improve locally developed genetic material. This will make the current sugarcane production system more sustainable and environmentally friendly. At farmer level, these efforts will translate into reduced production costs, higher yields and ultimately more profits.

Keywords: Sugarcane, Plant nutrition, Soil health, Crop productivity

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10. Climate Smart Agriculture: Way Forward for Ensuring Sustainable Food Security

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Abstract: Climate Smart Agriculture (CSA) is a holistic approach to transforming agri-food systems, addressing climate change, and ensuring food security and here are some key strategies such as Climate-Resilient Crops: Drought- and flood-tolerant crop varieties (e.g., rice, wheat, maize); Water Management: Efficient irrigation (drip, sprinkler), rainwater harvesting, and groundwater recharge; Soil Health: Conservation agriculture, organic amendments, and crop rotation; Agroforestry: Integrating trees with crops/livestock for carbon sequestration and biodiversity; Livestock Management: Improved breeds, feed efficiency, and waste management; Digital Tools: Weather forecasting, precision farming, and data-driven decision-making. The key benefits for adaptation of above strategies include Food Security: Enhanced productivity and resilience; Climate Mitigation: Reduced emissions (e.g., methane, nitrous oxide); Adaptation: Better coping with droughts, floods, and temperature stress; Economic Growth: Increased farmer incomes and rural livelihoods. The key challenges include Awareness Gap - Limited farmer knowledge of CSA practices; Financial Barriers - High upfront costs for technologies (e.g., solar pumps); Policy Support - Need for subsidies, insurance, and institutional frameworks. The Way Forward include Capacity Building - Train farmers, extension workers, and policymakers; Public-Private Partnerships - Invest in climate-smart infrastructure (e.g., greenhouses); Research & Innovation - Develop localized CSA solutions (e.g., heat-tolerant seeds); Policy Integration - Align CSA with national climate and food security goals

Keywords: Climate Change, Food Systems, Adaptation Strategies, Solutions

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11. Sustainable Weed Management in Wheat: Comparing Cross-Drill Planting and Chemical Weed Control

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Abstract: Weed infestation is one of the major constraints limiting wheat productivity in the Dera Ismail Khan, South KPK, Pakistan, due to severe competition for nutrients, moisture, light, and space. To evaluate the effectiveness of integrated weed management practices on weed dynamics, crop growth, nutrient uptake, yield attributes, yield, and economics of wheat cultivation. This study evaluated the effectiveness of cultural and chemical weed management practices during the 2022–2023 Rabi season at the Arid Zone Research Centre, Dera Ismail Khan, Pakistan. The experiment compared untreated control, cross-drill sowing (15 × 15 cm), hand weeding, and several herbicide treatments (Clincher, Walter Super, Buctril Super, Super Power Killer, and Ally Max). Among all treatments, cross-drill sowing produced the highest grain yield (7.59 t ha^{-1}), biomass yield (7596.7 kg ha^{-1}), spike density (512 spikes m^{-2}), grains per spike (33.3), and crop growth rate (26.97 g m^{-2} day^{-1}), while also achieving the greatest economic return. Herbicide treatments improved wheat performance compared with the untreated control but remained less effective than the cross-drill method. The untreated control recorded the lowest grain yield (6.87 t ha^{-1}), spike density (172 spikes m^{-2}), and crop growth rate (13.47 g m^{-2} day^{-1}). The findings demonstrate that cross-drill sowing effectively suppresses weed competition and enhances wheat productivity while reducing dependence on chemical herbicides. This eco-friendly and economically viable practice offers a sustainable approach to weed management and supports environmentally responsible wheat production.

Keywords: Herbicides, Mechanical practices, Sustainable agriculture, Weed management, Wheat farming

12. Scaling Digital Agriculture for Food Security: 17 Years of Digitalization for Climate Resilience (2009–2026)

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Abstract: Accelerating climate variability poses severe threats to global food security, demanding scalable, climate-smart agricultural interventions. This paper synthesizes a 17-year global journey (2009–2026) applying digital tools across diverse cropping systems and livestock environments to enhance climate resilience. Tracing the technological evolution from early static models to real-time IoT, predictive analytics, and automated decision-support systems, we critically evaluate how digital solutions translate into field-level impacts across distinct geographical contexts. Drawing from hands-on case experiences across Asia and South America, this study highlights diverse cross-commodity applications: optimizing phenology-driven sowing and drip irrigation scheduling via APSIM cotton modeling in China; implementing soil moisture sensor networks and rainwater harvesting frameworks for drought mitigation in Pakistan; integrating climate tools and soil sensors for grassland and livestock management in China; precision sugarcane seeding and variable-rate input systems in Brazil; and digitizing decision workflows for organic farming systems. Synthesizing nearly two decades of field-level implementation, we examine how coupling digital tech such as soil sensors, climate modeling, and smart irrigation schedules-consistently boosts yield stability, water-use efficiency, and input optimization under high climate stress. Crucially, the study addresses systemic hurdles to scaling, including environmental harshness on field hardware, data interoperability, and adoption barriers across different farming scales. Ultimately, this 17-year multi-crop, multi-region retrospective provides a pragmatic blueprint for leveraging digital agriculture as an indispensable catalyst for long-term food security and global climate resilience.

Keywords: Climate Resilience; Digital Agriculture; APSIM Model

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13. Enhancing Cereal Drought Resilience through Deeper and Dense Rooting

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Abstract: This study evaluated how biological (lucerne as pre-crop) and technical (strip-wise deep tillage with compost) subsoil amelioration strategies modify root length density (RLD) and rooting depth and thereby influence drought resilience in cereal crop under field conditions in Germany. The field trials were carried out in 2020 and 2021. Roots were sampled using the soil monolith method in both years; RLD was estimated by manual root counting in 2020 while root length in 2021 was quantified from soil-profile images using RootPainter, an open-source, deep-learning image-analysis software based on a U-Net convolutional neural network. The software was trained through an interactive corrective-annotation procedure: initial root and soil regions were manually labelled, after which the model's predictions were repeatedly corrected. Once sufficiently trained, RootPainter automatically segmented roots from the large image dataset, enabling rapid quantification of root length while reducing the time and subjectivity associated with manual root counting. Lucerne followed by deep tillage and compost significantly increased the subsoil RLD and maximum rooting depth, particularly below 60 cm, enhancing extraction of stored subsoil water and nutrients during dry period. This root growth improvement translated into higher grain yield and yield stability in spring barley under drought, whereas winter wheat showed limited response in wetter year, highlighting that benefits are strongest when water is limiting and for spring-sown cereals (short growing season). Overall, the findings demonstrate that integrated strategies which increase RLD and extend rooting depth into the subsoil can enhance drought resilience and productivity in cereal crops, provided they are matched to appropriate species, varieties, and seasonal moisture conditions.

Keywords: Root length density (RLD), Rooting depth, Drought resilience, Cereal crops, Subsoil, Deep tillage, Pre-crop, Spring barley, Winter wheat

14. Machine Learning with Hybrid Feature Selection and Multi-Task Learning for Multi Trait Wheat Genomic Prediction

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Abstract: Wheat breeding requires robust and accurate selection of superior genotypes. Genomic prediction can support this process using SNP marker data. However, genomic datasets often contain thousands of markers. Many markers may be redundant or weakly informative. This can reduce model efficiency and increase the chances of over-fitting. This study presents a machine learning framework for multi trait wheat genomic prediction. The framework applies hybrid feature selection to identify informative SNP markers related to abiotic/biotic stresses for developing climate smart crop varieties. Different feature selection methods are combined to improve marker screening. The selected SNPs are then used for phenotype prediction. Several machine learning and deep learning models are evaluated. These include regularized regression, Random Forest, gradient boosting, support vector regression, and neural networks. Multi task learning is also used to predict several agronomic traits together. This allows the model to use relationships among related traits during training. Model performance is evaluated using cross validation, Pearson correlation, RMSE, MAE, and prediction stability. The effect of SNP reduction on prediction accuracy and computational cost is also examined. The framework can support faster screening of wheat germplasm. It can help breeders identify promising genotypes at earlier stages. It can also reduce the complexity of genomic data. This may improve breeding efficiency and accelerate genetic gain. The approach can support climate smart wheat improvement and sustainable food security.

Keywords: climate smart breeding, genomic selection, hybrid feature selection, machine learning, multitask learning, multi trait prediction, SNP markers, wheat genomic prediction

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15. Evaluation of CropSyst and DSSAT Models for Sunflower (*Helianthus annuus* L.) Yield under Rainfed Conditions of Pothwar

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Abstract: Sunflower is an important oilseed crop that is highly vulnerable to climate variability. Accurate crop simulation modelling is therefore essential for optimizing agronomic inputs and reducing climate-related production risks. This study evaluated the performance of two widely used crop simulation models, CropSyst and DSSAT, in simulating the growth, phenology, and achene yield of sunflower under semi-arid rainfed conditions. A field experiment was conducted during the spring season of 2017 at two locations in the Pothwar plateau of Pakistan: National Agricultural Research Centre (NARC), Islamabad, and the University Research Farm (URF-Koont), Chakwal. The experiment was laid out in a split-plot factorial design with three replications, comprising three sunflower hybrids (KSF-2815, Parsun-3, and T-40318), three row spacings (45, 60, and 75 cm), and four nitrogen levels (0, 60, 120, and 180 kg N ha^{-1}). Observed data on anthesis, physiological maturity, aboveground biomass, yield components, and achene yield were compared with model simulations. Favourable growing conditions at NARC were associated with significantly higher biomass, achene yield, and head diameter than at URF-Koont. Among hybrids, KSF-2815 produced the highest achene yield, whereas T-40318 recorded the greatest shoot length and biomass. Narrower row spacing (45 cm), reflecting higher plant density, and nitrogen application of 120-180 kg N ha^{-1} substantially improved crop productivity. Model performance was evaluated using the coefficient of determination R^2. Both CropSyst and DSSAT satisfactorily simulated sunflower phenology, biomass accumulation, and achene yield across locations and management treatments. DSSAT generally showed slightly closer agreement with observed data (R^2= 0.89-0.99) than CropSyst (R^2= 0.87-0.98). However, the performance of both models was comparable and within acceptable limits. These results indicate that, after site- and cultivar-specific calibration, DSSAT and CropSyst can serve as useful decision-support tools for evaluating nitrogen management and plant population density in rainfed sunflower systems, although further validation across seasons and independent environments is recommended before broader application.

Keywords: Crop simulation models, DSSAT, CropSyst, Rainfed agriculture, Pothwar, Sunflower

16. Life Cycle Assessment Modeling and Energy Analysis of Solar-Powered Tubewells for Sustainable Irrigation

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Abstract: Agriculture is one of the key sectors of the economy in Pakistan and irrigated agriculture is an important source of its agricultural output, especially in Punjab Province. Though the tubewells are widely used for irrigation, traditional diesel and electricity powered systems are expensive, emit greenhouse gas (GHG) and are environmentally problematic. Using solar-powered tubewells also provides a more sustainable and less polluting method of groundwater irrigation. This study intends to examine environmental and thermodynamic performance in solar powered tubewells by integrated Life Cycle Assessment (LCA) and energy analysis. Fifteen solar-powered tubewells in Multan, Punjab were selected and field data were recorded. Results of the LCA indicated that the GHG emissions from solar-powered tubewells were significantly low as compared to the conventional irrigation systems. Emissions from the manufacturing phase accounted for the highest share (46%) of total emissions, and the operational phase had near to zero direct emissions. The results of sensitivity analysis showed that pump efficiency and lifetime of the system are the most important parameters that affect the environmental performance. The average efficiency of solar powered tubewells was 39.4% as against 26.6% for the tubewells powered by diesel engine. A significant energy loss was related to PV panels, pumps and motors which revealed opportunities for the improvement of these parts and optimization of the system. The integrated assessment highlighted the environmental and thermodynamic benefits of using solar energy for irrigation. The results suggested that the solar tubewells can be promoted by addressing system design, proper maintenance, providing incentives and implementing policies. The use of this technology could be a way to minimize reliance on fossil fuels and promote sustainable groundwater management and climate-smart agriculture in Pakistan.

Keywords: climate-smart agriculture; energy analysis; greenhouse gas emissions; life cycle assessment; solar-powered tubewells; sustainable irrigation

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17. On-Site Precise Nitrogen Management in Cotton through Satellite Imagery

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Abstract: Cotton (*Gossypium hirsutum* L.) is a vital cash crop in Pakistan, significantly contributing to its agricultural economy. Nitrogen (N) is essential nutrient for cotton growth, influencing yield and productivity. However, inefficient N management and over application can lead to reduced N use efficiency (NUE), negatively impacting crop productivity and resulting in environmental degradation. This study explores the use of satellite-derived Normalized Difference Vegetation Index (NDVI) data from Sentinel-2 and Landsat-8 derived imagery, to optimize N application in cotton cultivation. In this research trial, nitrogenous fertilizer application was comprised of T1= 190 kg N ha^{-1}, T2= 247 kg N ha^{-1} (Control), T3= 315 kg N ha^{-1}, T4= N application as per Sentinal-2 and T5= N application as per Landsat-8. Each treatment was replicated three times in an RCBD design. The research examines the effects of NDVI-guided nitrogen rates on phenological, physiological and yield parameters. At 60 DAS, Sentinel-2 recorded an NDVI of 0.41, while Landsat-8 recorded 0.33, with Sentinel-2 showing better vegetation density. At 120 DAS, Sentinel-2's NDVI increased to 0.68, compared to 0.60 for Landsat-8, indicating improved vegetation health with Sentinel-2. The results showed that NDVI-guided treatments significantly improved NUE, with T4 achieving the highest seed cotton yield of 2702 kg ha^{-1}, a18.29% increase over T1 (2285 kg ha^{-1}). Regarding biological yield, T3 recorded 9466 kg ha^{-1}, followed by T2 with 8476 kg ha^{-1}, while T1 had the lowest at 5437 kg ha^{-1}. Economic analysis of treatment supported these findings with T4 had the highest benefit cost ratio, followed by T5, while T1 had the lowest. Overall, this study demonstrates that satellite-based nitrogen management through satellite imagery, particularly using Sentinel-2 NDVI data over Landsat-8 derived NDVI and other traditional nitrogen application rates, enhances NUE and cotton productivity, contributing to more sustainable farming practices and precision agriculture.

Keywords: Landsat-8; NDVI; NUE; Sentinal-2

18. Machine Learning Based Estimation of Evapotranspiration Through Multisource Data

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Abstract: Evapotranspiration (ET) is a significant part of the water cycle on land, and it has a critical role in water management, irrigation scheduling, and hydrological modelling in agriculture. Given the high demand for water in the agriculture sector in Pakistan (over 90% from freshwater resources), the need for spatiotemporal estimation of ET is growing in importance. The goal of this research is to design and test ET estimation models based on the machine learning method with satellite data from WaPOR and ancillary meteorological and remote sensing data, enabling data-driven learning from complex, nonlinear ET patterns across diverse agro-climatic conditions. The study employs several ML algorithms to estimate ET in the representative agro-climatic regions of Pakistan. The proposed models are trained using multiple satellite data sources as well as meteorological data to identify spatio-temporal patterns in ET. Model validation is performed using eddy covariance flux tower measurements and other ground-truth data. Model performance is evaluated using statistical metrics like R^2, RMSE, and MAE. However, ET monitoring is still difficult because the networks of ground-based observations are not dense enough, and point-scale observations like EC flux towers are limited in spatial extent gaps that machine learning approaches trained on remote sensing data are well-positioned to bridge. The findings of this study are expected to enhance water use efficiency, water resource management, and evidence-based agricultural planning in the highly water-intensive regions of Pakistan.

Keywords: Evapotranspiration ET, EC Flux Tower, Water Management, Irrigation Scheduling

19. From Trap Image to Spray Decision: Trap Specificity as the Limit of Machine-Vision Insect Surveillance in Climate-Smart Pest Management

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Abstract: Automated insect counting has advanced faster than the entomology needed to interpret the counts. In smallholder maize and cotton systems of South Asia, where *Spodoptera frugiperda* (J. E. Smith) is now established and *Bemisia tabaci* (Gennadius) drives repeated insecticide use, scouting is labor-intensive and observer-dependent, which explains the interest in image-based surveillance. Convolutional neural networks applied to trap images detect moths and small Hemiptera with high accuracy under controlled imaging. Performance falls when debris, overlapping specimens, variable light and unfamiliar field backgrounds are introduced. This synthesis proposes that much of the difficulty is set before any algorithm runs, by the specificity of the trap. Pheromone-baited traps for *S. frugiperda* deliver large, single-species targets with consistent morphology. Non-specific sticky traps for *B. tabaci* adults, about one millimeter long, deliver crowded images of mixed taxa that include natural enemies, and the cryptic species within the *B. tabaci* complex cannot be separated from an image at all. Trap catch is also climate-confounded, because adult flight activity responds to temperature, wind and crop stage, so identical counts can represent different population densities. A second gap lies downstream. Detection accuracy is usually reported as precision or recall, whereas a grower needs a spray decision. The relation between moth catch and later larval damage is inconsistent, and sticky-trap catches of adult whiteflies do not measure nymphal density on leaves. These are evidence limits, not technical details. Sensing-to-decision pipelines could reduce unnecessary insecticide applications, scouting labor and delays in early warning for range-shifting pests, provided they run on low-cost hardware with limited connectivity. Validation should therefore report decision-level outcomes rather than detection scores alone, including weather covariates, verify identity by molecular subsampling, and extend across several seasons on smallholder farms.

Keywords: Machine vision; pest surveillance; trap specificity; *Spodoptera frugiperda*; *Bemisia tabaci*; decision support

20. Remote Sensing, Drones and Artificial Intelligence for Climate-Resilient Pest Monitoring and Early Warning

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Abstract: Climate change is increasing the frequency, speed and unpredictability of insect pest outbreaks, while conventional field scouting remains labor-intensive, slow and limited in spatial coverage. Digital technologies offer a practical way to improve timeliness and accuracy of pest monitoring. This paper reviews the application of remote sensing, unmanned aerial vehicles (drones) and artificial intelligence (AI) for detecting, monitoring and forecasting insect pests in crops and orchards. Satellite and drone-mounted multispectral, hyperspectral and thermal sensors can identify crop stress, canopy damage and infestation hotspots before symptoms are visible to the human eye. High-resolution drone imagery supports site-specific scouting of large or inaccessible areas and enables targeted rather than blanket pesticide applications. Machine learning and deep learning models, including convolutional neural networks, are increasingly used to classify pest species, count insects from trap images and predict outbreak risk by combining imagery with weather, soil and historical pest data. Integration with smart traps, Internet of Things sensors and mobile advisory platforms allow near real-time decision-making by farmers and extension workers. These tools reduce unnecessary insecticide use, lower costs, and help protect pollinators and natural enemies within climate-smart Integrated Pest Management (IPM). However, major challenges remain, including high equipment costs, limited training datasets for local pests, regulatory restrictions on drone use, and low digital literacy among smallholder farmers. We conclude that affordable, locally validated and farmer-friendly digital monitoring systems, supported by capacity building and policy backing, are essential to strengthen early warning and build resilient plant protection systems.

Keywords: Remote sensing, Drones, Artificial intelligence, Pest monitoring, Early warning, Climate-smart IPM

21. Remote Sensing and Crop Modeling for Climate-Smart Decision Support in Agriculture

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Abstract: Climate change is increasingly threatening agricultural productivity through rising temperatures, irregular rainfall, water scarcity, and frequent drought and heat stress. These challenges require innovative and timely approaches for improving farm-level decision-making. The integration of remote sensing and crop modeling provides a promising pathway for developing climate-smart agricultural strategies. Remote sensing technologies provide timely information on crop growth, vegetation health, water stress, and spatial variability. Crop simulation models such as DSSAT (Decision Support System for Agrotechnology Transfer) simulate crop phenology, biomass accumulation, and yield formation in response to weather, soil, genotype, and management practices, including sowing date, nitrogen, and irrigation. When DSSAT is combined with satellite-derived vegetation indices, such as NDVI and LAI from Sentinel-2, and meteorological data, model calibration, spatial yield estimation, and crop monitoring can be improved. This integration also supports yield forecasting and the efficient management of irrigation and nutrients. Moreover, it can evaluate potential climate change impacts and identify suitable management strategies for maintaining crop productivity under changing environmental conditions. By providing location-specific, data-driven information, this approach can support farmers, researchers, and policymakers in informed decision-making. Overall, the integration of remote sensing and crop modeling offers a powerful tool for promoting climate resilience, resource-use efficiency, and sustainable production, particularly in climate-vulnerable and water-limited regions.

Keywords: Climate change; Remote sensing; Crop modeling; DSSAT; Sentinel-2; Food security

22. Hyper-spectral and Multi-spectral Imaging Advancements in the Field of Agriculture and Early Disease Recognition in plants

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Abstract: The goal of modern agricultural identification and recognition techniques is simply to be non-invasive and non-destructive to the plant itself. Among these emerging optical sensing technologies, Hyper-spectral imaging (HSI) and Multi-spectral imaging (MSI) are promising owing to their benefits such as in-depth ability to detect and record narrow, contiguous spectral bands that are not visible to the human eye. This technology is useful in measuring and observing various cellular level qualities of the plants. These include but are not limited to; cellular structure, chlorophyll content, pigmentation, water activity and more. As a consequence of this observation of internal, integral parts of a plant, its health and risks of future disease development can be detected, even before the visible symptoms begin to manifest. The scope of this technology has been greatly utilized by the introduction of Unmanned Aerial Vehicles (UAVs), automated robotic farming equipment, miniature sensors and improved spatial-spectral resolution to reach and observe a large area of crops. Artificial Intelligence (AI) has been a consistent part of handling, working of and overall algorithms of these robots. Dimensionality reduction frameworks have been able to condense extensive raw datacubes into much more analyzable and understandable sets of data. This ensures added convenience to the whole process of pattern recognition and disease identification, while simultaneously reducing workload of the farmers. Although hyper-spectral sensors have simplified the detection of fine physiological differences, multi-spectral systems offer high spatial resolution and more efficient solutions appropriate for commercial scale. The HSI and MSI techniques are effective in post-harvest assessment of quality, estimating crop yield and ensuring the specialized uses of industrial grade pesticides and fertilizers. Though consistently being introduced to majority of the world, the technology still falters when it comes to issues like data redundancy, environmental rejection, pollution related concerns, high maintenance costs, unavailability of hardware and constant calibration. Keeping rapid development in mind, the future is expected to bring forth the integration of edge computing, addition of multipurpose sensors and much easier to use software for this equipment that will provide improvement in the field of non-invasive disease detection among plants.

Keywords: Precision agriculture, Image analysis, Hyper-spectral imaging (HSI), Multi-spectral imaging (MSI

23. Spatial Variability of Soil Physico-Chemical Properties in Hill Torrent Command Areas of Punjab, Pakistan

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Abstract: Soils in arid to semi-arid areas in many countries around the world, which receive hill torrents are continually under threat of soil loss, rendering fertile and productive lands barren over time. Mapping of soil properties contributes to better management practices leading to enhanced crop production. This study examined the influence of altitude on the physico-chemical qualities of soil in 13 hill torrent affected regions of Dera Ghazi Khan and Rajanpur from the Sulaiman range. The 351 soil samples from 3 soil depths (0–15 cm), (16–30 cm), and (31–45 cm) were taken at three altitudes of each hill torrent command area. Portable GPS coordinates were collected for each elevation and hill torrent location. Physico-chemical soil parameters were determined using standard procedures. For this investigation, a representation of soil parameters was created using the ArcGIS 10.2 software. The soil was sandy in the upper elevated command areas of most of the hill torrents except Pitok and gradually became loamy to clay loam in the lower command areas. Other soil attributes were better at higher elevations except for total nitrogen, which probably leached under heavy hill torrent flows. Bulk density ranged between 1.56 in upper slope of Sanghar to 1.36 g cm^3 in lower slope of Zangi; interaction of Soil pH ranged from 8.81 in Vidor at upper elevation at upper 15 cm soil depth to 7.9 in Chachar at lower elevation and 31-45 cm soil depth. Whereas interaction of organic matter ranged from 1.23% in Suri Shumali at upper elevation with upper 15 cm soil depth to 0.15% in Suri Janobi at lower elevation with 31-45 cm soil depth. With increasing soil depth from the surface (up to 45 cm), the soil properties deteriorated in terms of supporting plant growth based on soil texture and likely presence of hard plough pan. There were marked differences for various soil fertility parameters across soil depths and hill torrent sites. Moreover, good crop production is possible in hill torrent command areas of Punjab, Pakistan.

Keywords: Hill torrent, geospatial analysis; GIS; GPS; soil properties; spate irrigation

24. Tillage Practices Affect the Soil Health, Water Use Efficiency and Yield of Lentil in Hill Torrent Area of District Dera Ghazi Khan, Pakistan

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Abstract: Pre- and post-flood tillage practices were evaluated in field studies for their effects on soil health, soil water use and lentil productivity in the Mithawan hill torrent irrigated region at two sites in Dera Ghazi Khan Punjab (Pakistan) for two consecutive years. Pre-flood tillage treatments included mouldboard plough, chisel plough, disc plough, cultivator and farmer's practice (fallow). While post-flood tillage treatments comprised of cultivator; cultivator and rotavator. Soil moisture availability at flowering stage increased from 23.38% at 0-15 cm to 26.50% at 31-45 cm at site 1 during the first year. At site 2, the respective increase across increasing depth was 23.44% to 26.18%. Water productivity in chisel plough run fields as pre-flood treatment increased to 0.04 and 0.043 kg m^3 at site 1 and 2, respectively during the first growing season.; however, the bulk density at site 1 reached 1.45 g cm^3 and 1.41 g cm^3 at site 1, and 1.44 g cm^3 and 1.42 g cm^3 at site 2, respectively. Moreover, soil EC_e and pH were reduced after the cultivation of lentil at both sites irrespective of the treatments employed. Seeds per pod (1.93), during the 1st year (site 2); the heaviest 1000 grains (21.49g) during the 1st year (site 2) and seed yield during 1st year (420.7 and 456.3 kg ha^{-1}) and 2nd year (91.1 and 73.0 kg ha^{-1}) at site 1 and 2, respectively were highest in the chisel plough run plots. The highest benefit-cost ratios (1.2 and 1.4) were recorded from the same chisel plough run fields as pre-flood tillage practice followed by cultivator as post-flood tillage practice at site 1 and 2 during 2019-20, respectively. Farmers in Mithawan hill torrent command areas of Dera Ghazi Khan can have better soil moisture use for improved lentil productivity during reasonable soil water supplies. Moreover, because this area has been little researched for lentil hence more research is highly advocated for standardization of agronomic interventions besides development and provision of adaptable high yielding promising climate smart cultivars for the hill torrent hit ecologies.

Keywords: Hill torrent, lentil yield, pre- and post-flood tillage, spate irrigation, water productivity

25. Arbuscular Mycorrhizal Fungi and Organic Farming

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Abstract: Arbuscular mycorrhizal fungi (AMF) play a vital role in organic farming by enhancing soil fertility, improving plant nutrient uptake, and promoting crop resilience to environmental stresses. These beneficial fungi form mutualistic associations with plant roots, facilitating the absorption of essential nutrients such as phosphorus, nitrogen, and micronutrients while also improving soil structure and water retention. In organic farming systems, where the use of synthetic fertilizers and pesticides is restricted, the AMF can contribute significantly towards soil health and crop productivity by fostering natural nutrient cycling and supporting beneficial soil microbial communities. Additionally, the AMF enhance plant tolerance to abiotic stresses like drought, salinity, and heavy metal toxicity, as well as biotic stresses caused by pathogens and pests. Their ability to improve soil aggregation and carbon sequestration further strengthens their role in sustainable agriculture. However, the effectiveness of AMF in organic farming depends on soil conditions, crop species, and management practices. This study explores the mechanisms through which AMF enhance plant growth and soil health in organic farming systems. It also discusses strategies for optimizing AMF inoculation, challenges associated with their large-scale application, and future research directions. The integration of AMF-based biofertilizers and management practices tailored to organic agriculture can help reduce dependency on external inputs while maintaining high crop yields. By harnessing the potential of AMF, organic farming can move toward more sustainable and resilient food production systems, ensuring long-term agricultural sustainability and environmental conservation.

Keywords: nutrient uptake; plant–microbe interactions; sustainable agriculture; soil fertility

26. Maize Cultivation and Consumption Practices in Azad Jammu and Kashmir: Insights from Farmers

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Abstract: Maize (*Zea mays* L.) has historically been a cornerstone of agriculture in Azad Jammu and Kashmir (AJK), serving as a primary food source and essential livestock feed. This study investigates the current farming practices and consumption patterns of maize across AJK's major maize-growing regions. A three-stage stratified random sampling method was employed to select a sample of 175 respondents, and descriptive statistics were used for data analysis. The findings reveal that traditional maize varieties continue to dominate cultivation practices, with 59% of the farmers opting for these varieties. On an average, farmers used 3.41 kg of seed per kanal, and the application of chemical fertilizers was minimal, while pesticide use was reported as nonexistent. Despite these traditional methods, an average yield of 401 kg per acre was recorded, although lodging remains a significant challenge hindering higher productivity. Regarding consumption patterns, approximately 82% of the maize crop is being consumed domestically, highlighting its continued importance in local diets. A smaller proportion, 6%, is used for seed, and only 10% is sold to other farmers or in markets. These findings underscore the enduring significance of maize as a staple food and its integral role in agricultural livelihoods in AJK. This study provides insights into the current state of maize farming in AJK, emphasizing the need for sustainable agricultural practices to address productivity challenges and ensure food security. It also suggests the avenues for future research and policy interventions aimed at enhancing maize cultivation techniques and promoting economic resilience among farming communities in the region.

Keywords: farmer's habits, maize cultivation, socio-economic factors, yield challenges

27. Nutrition-Sensitive Climate-Smart Agriculture: A pathway towards Sustainable and Healthy Food Systems

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Abstract: Climate-smart agriculture (CSA) is an important strategy to sustain agricultural productivity, adapt to climate change and lessen the impacts on natural resources. But the key element in sustainable food systems is not just that there is enough food, but that it is available in safe, diversified and nutritionally adequate diets. Nutrition sensitive CSA incorporates nutrition goals into the design of food systems and agricultural production. Diversification of crops and livestock, better land and water utilization, climate-smart farming and production methods, and sustainable use of local food resources can help to make more nutritious food available. These can help increase protein, dietary fiber, vitamin and mineral intake and help to decrease reliance on limited food commodities. It is critical in developing countries, especially Pakistan, to include nutrition in climate adaptation measures as climate-related shocks can have disproportionate impacts on households facing constraints in accessing a variety of foods. Better connecting agricultural production with food processing, markets, and nutrition education will help to further strengthen the linkages between agricultural diversity and healthier diets. Nutrition sensitive CSA is therefore seen as an integrated approach to address the interconnected challenges of climate change, food security, malnutrition and sustainable use of resources. A more integrated approach between the agricultural and nutrition sectors can help to build resilient food systems that can satisfy current and future nutrition needs.

Keywords: climate-smart agriculture, dietary diversity, food security, malnutrition, nutrition-sensitive agriculture, sustainable food systems

28. Climate Change and its Implications for Food and Nutrition Security in Pakistan

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Abstract: The effect of climate change on food production, food availability and nutrition quality is growing in importance, and thus has potential to risk food security in Pakistan. Changes in temperature, irregular rains and droughts, floods and limited water availability can impact cereals, fruits, vegetables, pulses, and other foods that are rich in nutrients. These changes are likely to raise food prices and make it harder for people, especially vulnerable populations, to have access to a wide range and diversity of diets. Climate-smart agriculture offers a nutrition opportunity to achieve both food production and nutritional outcomes through diversified cropping systems, water-efficient agriculture, developing climate-resistant food crops and adopting sustainable practices. Incorporating nutrition into food system planning to a higher degree would create a transition from a primary focus on calories to production of a variety of nutrient-dense foods. Nutrient sensitive agricultural interventions such as diversification of food production, encouraging the use of locally available nutrient rich foods, reducing post-harvest losses, and improving food processing and storage, can help to build resilient food systems. More effective coordination of nutritionists, agricultural scientists, policy makers and the farming community will be required to enable the design of sustainable approaches that will safeguard dietary quality in the face of climatic variability. This approach of embedding nutrition into climate smart agriculture can thus offer a potential pathway in enhancing food security, dietary diversity and population health in the long-term in Pakistan.

Keywords: climate change, nutrition security, food security, dietary diversity, climate-smart agriculture

29. Biofortification as an Innovative Approach to Combat Hidden Hunger

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Abstract: Hidden hunger, which is caused by the deficiency of essential micronutrients, is a serious problem in developing and low-income countries. The lack of nutrients such as iron, zinc, and vitamin A can have negative effects on health and development. Micronutrient biofortification is an innovative and sustainable approach that improves the quality of food crops at the point of consumption. Unlike traditional methods of food fortification, crop biofortification enhances the micronutrient density and bioavailability in staple crops through agricultural and plant breeding techniques. It is an effective measure that can help address the problem of hidden hunger as well as reduce the prevalence of micronutrient malnutrition in the developing world. Moreover, it is more cost-effective and can be easily adopted at large to improve the dietary intake of the targeted nutrient-deficient populations. Overall, increasing the micronutrient density of crops is a valuable investment that can improve dietary quality, food security, and public health while decreasing the negative effects of micronutrient malnutrition on development and health outcomes.

Keywords: bio fortification, hidden hunger, micronutrient deficiency, food and nutritional security, nutrient enriched crops, sustainable agriculture, food fortification, public health.

30. Comparative Evaluation of Water and Energy Use Efficiency of Responsive and Subsurface Drip Irrigation Systems

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Abstract: In southern Punjab, Pakistan, an area with limited water resources, efficient use of water and energy is crucial for sustainable agriculture. Traditional irrigation methods tend to be inefficient, wasting water and energy, which drives up production costs and lowers productivity. This study was conducted to assess the water use efficiency (WUE), energy use efficiency (EUE) and crop yield of Responsive Drip Irrigation (RDI), Subsurface Drip Irrigation (SDI) and conventional surface irrigation in tomato growing in Muzaffargarh, Punjab. Randomized Complete Block Design (RCBD), 3 treatments, three replications were carried out in the field during spring growing season (February to May). Flow meters were used to measure irrigation water consumption and energy meters were installed on solar-powered pumping units for energy consumption. The tomato yields were measured at harvest for the determination of WUE and EUE. The results indicated that RDI resulted in the highest WUE (19.97 kg m-3) and EUE (44.38 kg kWh-1) with 137.2% and 50.7% improvements, respectively, compared to the conventional treatment. The results showed that RDI gave a 25% increase in WUE and 24.5% increase in EUE over SDI. The yield of tomato was also increased 9.2 percent, to 29.7 tons per acre as compared to 27.2 tons per acre for SDI. The energy consumption was greatest in April when the fruits were in the development stage, and the energy consumption was 16.6–26.5% lower for RDI during other months. The results showed that RDI increased the productivity of water and energy and kept the yields high. The study demonstrates that responsive irrigation technologies can be used to save agricultural resources and realize climate-smart and sustainable tomato production in the region of Punjab.

Keywords: responsive drip irrigation; subsurface drip irrigation; water use efficiency; energy use efficiency; tomato production; climate-smart agriculture; sustainable irrigation.

31. Linking Water Scarcity and Public Health: A Quantitative Risk Assessment and Policy Approach for Wastewater-Irrigated Agrifood Systems in Pakistan

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Abstract: Climate change leads towards significant increase in water shortage in Pakistan, leaving peri-urban and rural farmers no choice other than resorting to untreated municipal and industrial wastewater for crop irrigation. Although this strategy temporarily helps in maintaining the agricultural yield levels, but it impacts negatively on public health via contamination of food chain through introduction of heavy metal pollutants (i.e. Lead, Cadmium) and other microbial pathogens. The current governance framework considers water resource management and public health separately without having quantitative risk assessment techniques required to measure the health risk cost of such climate-smart yet unsafe agricultural strategies. This study aims to quantify the public health impact due to climate-adaptive wastewater irrigation in Pakistan and introduced an integrated "Safe Water-Safe Food" policy framework. In this study, systematic synthesis of secondary data and quantitative risk modeling are utilized. The methodology uses the secondary data on heavy metal concentrations (Pb, Cd, Cr) from PCSIR publications and peer-reviewed environmental research (2015-2025) In addition, the standardized World Health Organization (WHO) Human Health Risk Assessment model is used to estimate the Estimated Daily Intake (EDI), Target Hazard Quotient (THQ) and Hazard Index (HI) for heavy metal exposure through consumption of staple vegetables (e.g., spinach, tomato, radish). Spatial correlation analyses were undertaken to correlate these toxicological risks with district-level data of the Pakistan Bureau of Statistics (PBS) and provincial health departments analyses performed through Pearson's r and regression analysis. Vegetables grown from untreated sewage in peri-urban transit routes have Lead (Pb) and Cadmium (Cd) levels 2.5 to 3.8 times above WHO acceptable levels. Hazard Index calculation showed that there is a probability of chronic non-cancerous and cancerous health effects due to the calculated hazard index exceeding 1.0 value for resident population. Incorporation of toxicology results with the public health data shows that there is a positive statistically significant correlation ($p < 0.05$) between the HI and an increased local incidence of gastrointestinal disorders, skin conditions, and chronic renal conditions for high HI areas. Untreated wastewater as a measure for climate change adaptation is developing a silent public health concern and putting the sustainability and safety of agrifood systems at risk. The suggested integrated approach framework gives policymakers a tool based on quantifiable data to align their water monitoring with food security protocols. Adapting this approach will reduce the public health concerns related to wastewater utilization.

Keywords: water scarcity, public health risk assessment, agrifood system

32. Policy-Driven Verification of Agri-Food Supply Chains: A Digital Platform for Quantitative Distribution Fairness in Pakistan

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Abstract: Informal intermediary systems (arthis) and unverified pricing systems lead to various structural inequities and information asymmetries within Pakistan's agri-food supply chains. Smallholder farmers, who make up over 80% of the agricultural population, often do not have access to transparent, government-approved pricing and therefore face extreme value leakage and change of occupation. Government believes qualitative data that is derived by officials but does not have real time quantity data. This approach leads to a lack of end-to-end traceability, quantitative verification of distribution fairness, allowing hoarding and price gouging. The objective was to create a centralized digital platform where farmers have access to government-approved fair price bands and MSPs and all supply chain actors (middlemen, transporters and retailers) are mandatorily registered and verified. The idea was to give the government real-time access to the commodity flow to quantify distribution fairness, eliminate unverified margins, and reduce inequalities. By following a methodology where we used secondary data analysis and digital conceptual modeling, this research uses secondary data obtained from the Pakistan Bureau of Statistics (PBS) Wholesale and Retail Price Indices as well as from the Pakistan Agriculture Census (2020). Using the technological foundations consisting of three basic pillars, this research creates digital architecture for solving the issue of existing inequity in the market. These technological pillars include: (1) the transparent digital portal for official price list for the farmers; (2) digital onboarding (e-KYC) and logging transactions for all actors along the chain; (3) an algorithmic government dashboard that will provide information about the real-time commodity and financial flow. Quantitative analysis of the price data of PBS showed unverified system, small producers get below 30 percent of the total retail value of their produce. By adapting PDVP approach, we will be able to introduce centralized and verified digital portals that will lead to the reduction of information asymmetry up to 40 percent. From Qualitative market management to a transparent, digital verification process is crucial to attain real fairness in the agri-food system of Pakistan. The Policy-Driven Digital Verification Platform offers policymakers a scientifically backed and technology-driven roadmap to revamp the mandi system. Through digital traceability and enforcement of price lists approved by the government, the state can gain complete transparency of the agricultural value chain and enforce distributive justice quantitatively.

Keywords: PDVP (policy driven digital verification platform), mandi system, agri food system

33. Nano-Zinc Biofortification in Sorghum: An Innovative Approach towards Food and Nutritional Security

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Abstract: Zinc deficiency in soils and human diets continues to undermine sustainable agriculture and global food security, particularly in cereal-based production systems. Sorghum (*Sorghum bicolor* L.), as a staple and climate-resilient crop, has significant potential to tackle food security issues in arid and semi-arid regions; yet its grain zinc content is frequently insufficient to meet nutritional needs. Recent remarkable achievements in agricultural nanotechnology present new prospects for improving micronutrient delivery and crop biofortification. The possible involvement of nano-zinc (nano-Zn) in increasing zinc availability, plant uptake, and internal mobility within sorghum. Nano-Zn formulations, due to their small size and strong reactivity, may improve nutrient utilization efficiency by minimizing fixation losses and allowing for more effective root and foliar absorption. Improved zinc nutrition is linked to higher physiological performance, grain development, and nutritional quality of sorghum. The incorporation of nano-Zn-based techniques into sorghum production systems is a novel approach to enhance crop nutrition while also promoting sustainable and resource-efficient agriculture. Adoption of such technologies could help to alleviate hidden hunger and increase food and nutritional security, especially in developing nations. Rigorous research and appropriate applications are required to fully unravel the benefits of nanotechnology in sorghum-based farming systems.

Keywords: Sorghum; nanotechnology; zinc biofortification; food security

34. Structural Analysis and Design Optimization of a Rotary Pruner Cutting Blade Using Finite Element Analysis for Sustainable Orchard Mechanization

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Abstract: Mechanical pruning in orchards is very important in orchard canopy management, as it aids in operational efficiency, labor-saving, and sustainable fruit production in orchards including citrus, guava, olive and mango. Rotary disc pruners are often used for mechanical pruning, but the cutting blades are not necessarily designed with consideration to the operating loads that they will encounter in service, let alone to be structurally sound. This can result in overuse of materials, higher manufacturing costs, structural deformations or premature failure of the blade. The structure of a rotary pruner cutting blade was assessed and optimized based on finite element analysis (FEA) in ANSYS Workbench. A three-dimensional computer-aided design (CAD) model of the cutting blade was prepared, and suitable mechanical properties of steel were selected. Blade was tested under combined rotational and branch-cutting forces and cutting forces were assumed from the published shear strength characteristics of fruit tree branches. Under given loading and boundary conditions, static structural simulations were carried out, and the von Mises equivalent stress distribution, the total deformation, and the factor of safety were investigated. Various blade geometrical configurations were systematically evaluated and compared to find one that is structurally efficient with sufficient load-bearing capacity and with less material consumption. Comparative analysis was used to pinpoint critical stress concentration areas and provide insight into the effect of blade geometry on structural performance. The study has developed a simulation approach for structural verification and optimization of rotary cutting blades, which is helpful for the development of reliable, cost-effective and energy-saving pruning machines for orchard mechanization and climate-smart agriculture.

Keywords: Rotary pruner; Finite element analysis; ANSYS Workbench; Blade optimization; Mechanical pruning; Sustainable orchard mechanization.

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35. Advancing Food and Nutritional Security through Sustainable Agri-Food Systems in South Punjab, Pakistan

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Abstract: South Punjab is a major agricultural region of Pakistan and plays a vital role in national food production; however, its agri-food system faces increasing challenges from climate change, water scarcity, soil degradation, inefficient resource utilization, post-harvest losses, food waste, poverty, and inadequate access to diverse and nutritious foods. These challenges threaten both food availability and nutritional security, particularly among vulnerable rural and low-income populations. This study aims to explore integrated strategies for advancing food and nutritional security through sustainable and resilient agri-food systems in South Punjab. The proposed approach focuses on sustainable agricultural production, efficient water and soil management, crop diversification, reduction of post-harvest losses, household food-waste assessment, and valorization of agricultural and food-processing by-products. Attention was given to quantifying food and associated nutrient losses across household and food-system levels to identify opportunities for improving resource efficiency. Furthermore, locally available and affordable foods were evaluated to support the development of practical, portion-based dietary guidelines promoting healthy and sustainable consumption patterns. The integration of circular economy principles and value-added processing of agricultural residues can reduce environmental impacts while creating additional economic opportunities for farmers and rural communities. Climate-smart agricultural practices, digital technologies, improved supply-chain management, and stakeholder participation will further contribute to building resilient food systems. The study is expected to provide region-specific evidence for policymakers, researchers, agricultural stakeholders, and communities to improve food availability, nutritional quality, resource efficiency, and environmental sustainability. Ultimately, strengthening sustainable agri-food systems can contribute to improved livelihoods, reduced food waste, enhanced climate resilience, and long-term food and nutritional security in South Punjab, Pakistan.

Keywords: Food security, Nutritional security, Sustainable agriculture, Climate change, South Punjab, Pakistan

36. Detection and Quantification of Adulterants in Dried Fenugreek Leaves

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Abstract: Fenugreek (*Trigonella foenum-graecum L.),* commonly known as Kasuri methi, is a valuable culinary herb, but adulteration with cheaper leafy materials can compromise its nutritional and functional quality. This study was conducted to quantify adulteration in dried fenugreek leaves using berseem clover, spinach, coriander, and commercially available market samples. Fenugreek leaves were dried using microwave, hot-air, and sun-drying methods, followed by evaluation of proximate composition, phytochemicals, color characteristics, and diosgenin content. Microwave drying was found to be most effective, producing a moisture content of 5.6%. Adulteration significantly altered the nutritional and phytochemical characteristics of fenugreek. Pure fenugreek contained 27.20 ± 0.36 mg/g diosgenin, which decreased to 22.87 ± 0.45, 21.60 ± 0.40, and 21.17 ± 0.30 mg/g with increasing levels of berseem clover, spinach, and coriander, respectively. Combined adulteration reduced diosgenin to 20.87 ± 0.40 mg/g, while market samples showed the lowest values of 20.37 ± 0.66 and 18.80 ± 0.55 mg/g. Significant changes ($p < 0.05$) were also observed in protein, fat, phenolic and flavonoid contents, and color characteristics. The findings demonstrate that adulteration substantially affects the quality and authenticity of dried fenugreek leaves, while diosgenin can serve as a useful biochemical marker for detecting and quantifying adulteration.

Keywords: Fenugreek, Adulteration, Diosgenin, Kasuri methi, Dried leaves, Food authenticity

37. Improving the productivity of drought stressed fennel (*Foeniculum vulgare* mill) through foliar osmoprotectants

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Abstracts: Fennel **(***Foeniculum vulgare***)** is a highly versatile, medicinal and culturally significant plant. Drought stress significantly reduces overall growth, grain yield and quality of fennel (*Foeniculum vulgare*). This study was investigated to evaluate effectiveness of osmoprotectants against drought stress in fennel under Bahawalpur conditions. Different foliar osmoprotectants (F_0 Foliar spray of water, F_1 Foliar application of 2% potassium, F_2 Foliar application of 2% calcium, F_3 Foliar application of 20 mg/L proline and F_4 Foliar application of 20 mg/L glycine betaine) were applied on fennel at different level of drought stress (D_0 Application of 3 irrigations at vegetative, flowering and seed formation, D_1 Skipping of 1 irrigation at vegetative stage, D_2 Skipping of 1 irrigation at flowering stage and D_3 Skipping of 1 irrigation at seed formation stage). Application of odmoprotectants showed significant effect on growth and yield behaviour of fennel crop. Higher yield was recorded with foliar application of 2% K under drought stress at vegetative stage. The possible reason to enhance the yield of fennel is potassium (K) application. The finding of this study may be helpful for improving the yield and quality of fennel under drought and water limited condition in changing scenario of climate.

Keywords: Fennel (*Foeniculum vulgare* mill), osmoprotectants, drought stress, yield

38. Role of Strigolactones in Plant Responses to Drought Stress: Physiological and Molecular Mechanisms

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Abstract: Drought is one of the most critical environmental constraints affecting plant growth, productivity, and agricultural sustainability, with its frequency and severity expected to increase under climate change. Understanding the signaling mechanisms that coordinate plant growth and stress responses is therefore essential for developing effective strategies for drought-prone agricultural systems. Strigolactones (SLs), carotenoid-derived phytohormones and rhizospheric signaling molecules, have emerged as important regulators of plant development and adaptation to environmental stresses. Increasing evidence indicates that SLs play a multifaceted role in plant responses to drought by coordinating root system architecture, shoot growth, stomatal regulation, photosynthetic activity, and cellular redox homeostasis. Under water deficit, SL signaling is closely interconnected with abscisic acid, auxin, cytokinins, ethylene, and other regulatory pathways, enabling plants to balance growth and resource allocation with stress responses. In addition, SLs contribute to the regulation of reactive oxygen species (ROS) production and scavenging, thereby supporting antioxidant defense and protecting cellular structures from oxidative damage. At the soil–plant interface, SLs also influence arbuscular mycorrhizal associations and rhizosphere interactions, which may enhance water and nutrient acquisition under drought conditions. This study synthesizes current knowledge of SL biosynthesis and signaling in drought-stressed plants, with particular emphasis on the physiological and molecular mechanisms underlying SL-mediated regulation of water relations, photosynthesis, root development, hormonal crosstalk, and redox homeostasis. Finally, the potential of SLs and their synthetic analogs as promising tools for improving plant performance under water-limited conditions and contributing to climate-smart agricultural systems.

39. Lineage-Specific Heat Responses in the *Bemisia tabaci* Species Complex: A Missing Parameter in Climate-Smart Pest-Risk Forecasting

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Abstract: Warming is usually modelled as one temperature shift acting on one pest, yet the cotton whitefly *Bemisia tabaci* (Gennadius) is a complex of morphologically indistinguishable species that differ in thermal physiology, host use and insecticide response. The complex matters for food security because *B. tabaci* damages cotton, vegetables and pulses by phloem feeding and transmits begomoviruses, including those behind cotton leaf curl disease in Pakistan. Development, survival and fecundity follow thermal performance curves. Comparisons between the Middle East-Asia Minor 1 (MEAM1) and Mediterranean (MED) lineages indicate that heat survival, and the capacity to harden after sublethal exposure, differ between them. Comparable data for the Asia II lineages, which are prominent in South Asian cotton, remain sparse. Elevated temperature and CO_2 also alter host-plant nutrition and defense signaling, but the effect on whitefly performance varies with host species, plant age and population, so no general rule is supported. Temperature further changes insecticide toxicity and detoxification enzyme activity, which adds variance to control outcomes independent of resistance genes. Degree-day and distribution models usually apply one parameter set to the whole complex. This review argues that the assumption is the weakest link in current pest-risk forecasting. A shift in lineage composition under warming is a plausible hypothesis, but it has not been tested with controlled evidence and should not be read as an established trend. Three steps are testable. Lineage-resolved thermal performance curves should be built under fluctuating regimes that include heat-wave pulses. Field samples should be identified by mtCOI sequencing and recorded alongside temperature loggers. Host-by-temperature factorial assays should include virus transmission as a response variable. Until such data exist, advisories built on pooled parameters may misjudge the timing and composition of whitefly outbreaks in climate-vulnerable cotton systems. A standardized multi-site thermal dataset tied to molecular identity is the immediate priority.

Keywords: *Bemisia tabaci* species complex; thermal performance; pest-risk forecasting; begomovirus vector; climate-smart plant protection

40. Colour, Odour and Heat: Designing Climate-Robust Visual-Olfactory Traps for Non-Chemical Management of the *Bemisia tabaci* Complex

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Abstract

Insecticide sprays remain the default response to *Bemisia tabaci* (Gennadius), and resistance to neonicotinoids and other classes is documented in populations from several regions, including Pakistan. Behavioral manipulation offers a route to reduce that dependence, yet whitefly management has no field-validated pheromone lure comparable to those used against Lepidoptera. Whitefly host finding is a sequence. Long-range orientation is dominated by vision, with attraction to yellow-green wavelengths and avoidance of ultraviolet reflection. Short-range settlement is shaped by plant odor and leaf surface cues. Reflective mulches in open fields and UV-blocking cover in protected cultivation exploit the visual stage and delay virus spread, while yellow sticky traps serve mainly for monitoring, with supplementary suppression in protected cultivation. The olfactory stage is less developed. Host volatiles influence whitefly choice in laboratory olfactometers, and begomovirus infection can alter plant volatile emission and whitefly settling, although the direction depends on the virus, host and vector population. Evidence that odor enhances visual attraction at field scale remains thin. This review identifies a gap that is specific to climate. Plant volatile emissions rise with temperature and changes under drought and heat stress, and passive dispensers release faster in warmth. The odor background against which a lure must compete, and the dose it delivers, therefore shift across seasons and crop stages. A lure screened under one set of conditions may fail under another. A climate-robust design would test color and odor combinations across temperature ranges and plant physiological states, using population-specific assays, because responses are unlikely to be uniform across the *B. tabaci* species complex. The priority is a field-scale factorial comparison of visual cues, candidate volatiles and release rates across thermal regimes in cotton.

Keywords: Chemical ecology; plant volatiles; visual-olfactory orientation; non-chemical pest management; *Bemisia tabaci*

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41. Comparative Study of Nitrogen Application Techniques and Sources to Improve Cotton Productivity

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Abstract: Cotton (*Gossypium hirsutum* L.) is an important cash crop of Pakistan, but poor nitrogen (N) source selection and application method reduce N use efficiency (NUE), productivity and environmental sustainability. A field experiment was conducted at Muhammad Nawaz Shareef University of Agriculture, Multan in summer 2025 using a randomized complete block design with split-plot arrangement and three replications. Two N sources (urea and calcium ammonium nitrate, CAN) were tested under five application methods (surface broadcasting, placement at 5, 10 and 15 cm depth, and fertigation) at 220 kg N ha^{-1}. Emergence, flowering, boll formation and opening, physiological traits, yield, NUE and soil nutrient status were recorded. Fertigation raised the photosynthetic rate (13.37 µmol CO_2 m^{-2} s^{-1}) and chlorophyll index (46.00 SPAD) by 38.12% and 40.82% over surface application (9.68 and 32.67). CAN applied through fertigation gave the highest seed cotton yield (1600.00 kg ha^{-1}), 55.16% higher than surface-applied urea (1031.2 kg ha^{-1}), and the highest biological yield (4089.00 kg ha^{-1}). Its NUE was 7.10 kg lint kg^{-1} N, 51.38% higher than urea–surface application (4.69), while urea–banding recorded the highest benefit–cost ratio (1.20). In conclusion, CAN combined with fertigation was more effective than conventional urea broadcasting, providing a viable approach for efficient and sustainable cotton production.

Keywords: Nitrogen placement; nitrogen use efficiency; optimal fertilization depth; urea; calcium ammonium nitrate; cotton productivity

42. Climate-Smart Food Product Development for sustainable Agrifood Systems and Food Security

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Abstract: Climate change is a major threat to food security and is anticipated to impact agricultural productivity, availability of resources, crop quality and food system stability. Opportunities can be created for strengthening resilient and diversified agrifood systems through the sustainable utilization of climate-resilient crops and underutilized agricultural resources using innovative food product development approaches. Utilization of locally available plant resources, as well as cereals, millets, pulses, vegetables, and fruits, that provide high nutritional value in value added food products can contribute to better nutrition and efficient use of agricultural resources. Specific potential for the improvement of nutritional and bioactive properties of widely used foods is presented by composite formulations of flour and functional food products that allow reducing the use of resource-intensive conventional raw materials. These products can also help to add value to locally grown crops and provide opportunities for farmers, small-scale processors and businesses involved in food processing. The transition from primary agricultural production to higher-value food applications can also be supported by sustainable processing and formulation strategies that enhance product stability, quality, safety and consumer acceptance. Thus, the linkage of the increased availability of climate-resilient agricultural commodities and food product innovation can play a role in the efficient use of resources, dietary diversification, and access to nutritious food products. Practical strengthening of food systems under changing climatic conditions through development of affordable and nutritionally enhanced products from locally adapted agricultural resources. The integration of crops for climate-smart production and processing, sustainable processing and product development can complement resilient agrifood systems and contribute to long-term food and nutrition security.

Keywords: Climate-smart agriculture, Food product development, Food security, Value addition; Climate-resilient crops.

43. Mitigating the Adverse Impact of Drought in Maize Through Aloe vera Seed Priming and Its Subsequent Foliar Application

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Abstract: Drought limits maize productivity in arid and semi-arid regions, yet field evidence on combined Aloe vera seed priming and foliar application remains limited. This study evaluated their effectiveness in mitigating drought-induced losses in maize (*Zea mays* L.). A field experiment with hybrid P-1543 was conducted during spring 2025 at the Research Farm of MNS University of Agriculture Multan, Pakistan, using a randomized complete block design with a split-plot arrangement and three replications. Main plots received normal irrigation or drought imposed by skipping irrigation at the twelve-leaf (V12) stage. Ten subplot treatments comprised unprimed seed, hydropriming, and priming with 5%, 10%, or 15% Aloe vera extract, each with or without a subsequent 10% foliar spray. Agronomic, physiological, and gas-exchange traits were assessed using analysis of variance and Tukey's honest significant difference test ($p \leq 0.05$). Drought significantly reduced grain yield, leaf hydration, membrane stability, and photosynthetic activity. Priming with 15% Aloe vera extract followed by 10% foliar application recorded the highest grain yield averaged across water regimes (7.45 t ha^{-1}), 29.23% above the unprimed control. Under drought, this treatment yielded 6.88 t ha^{-1} compared with 5.56 t ha^{-1} in the control, while remaining statistically comparable with 10% priming plus the same foliar spray (6.76 t ha^{-1}). Leaf relative water content and membrane stability reached 87.92% and 56.30%, compared with 62.21% and 42.70%, respectively, in the drought-stressed control. Net photosynthetic rate and leaf relative water-use efficiency increased by 42.84% and 13.01%, respectively, relative to that control. Combined Aloe vera priming and foliar application offers a promising agronomic approach for improving maize productivity and physiological drought tolerance under limited irrigation, supporting climate-smart crop management. Validation across seasons, soils, and maize hybrids is required before wider adoption.

Key Words: Aloe vera; maize; drought stress; seed priming; foliar application; water-use efficiency

44. Sustainable Agrifood Value-Addition: Beetroot–Hibiscus-Enriched Gluten-Free Macarons for Enhanced Nutrition and Quality

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Abstract: Sustainable agrifood transformation demands nutrient-dense, clean-label product diversification to reinforce food and nutrition security. This investigation evaluated functional gluten-free macarons enriched with botanical powders from beetroot (*Beta vulgaris* L.) and hibiscus (*Hibiscus sabdariffa* L.) to achieve optimal functional enhancement without compromising consumer palatability. Formulations were developed by partially replacing almond flour with beetroot and hibiscus powders across varied ratios alongside an unfortified control. Samples were systematically assessed for proximate composition, DPPH antioxidant capacity, total phenolic content (TPC), pH, texture, mineral profile, color coordinates, FTIR spectra, and sensory acceptability across 14 days of cold storage. Higher fortification levels triggered pronounced darkening, excessive tartness, textural deterioration, and diminished hedonic scores. Consequently, the T1 formulation (10% beetroot + 5% hibiscus) emerged as the optimum treatment, delivering superior consumer acceptability alongside meaningful bioactive enrichment. Macarons produced under this best-performing condition maintained an optimal pH of 6.32 ± 0.02, elevated redness chromaticity (*a** value of 18.45 ± 0.28), DPPH free-radical scavenging activity of 20.15 ± 0.14%, and a total phenolic content of 65.80 ± 0.35 mg GAE/g. These findings confirm that integrating climate-resilient botanical adjuncts like beetroot and hibiscus into confectionery formulations supports sustainable agrifood systems by converting underutilized plant resources into high-value, clean-label functional foods.

Keywords: Agrifood sustainability; Antioxidant capacity; Beetroot (*Beta vulgaris*); Clean-label confectionery; Gluten-free macarons; Hibiscus (*Hibiscus sabdariffa*); Nutrition security

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45. Effect of Mulching and Nitrogen Levels on Weed Management and Productivity of Zero Till Cotton

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Abstract: Conservation agriculture practices like zero tillage, organic residue mulching, and balanced nitrogen management can improve soil health, suppress weeds, and enhance crop productivity. A field experiment was conducted at MNS University of Agriculture, Multan during 2025 to evaluate the interactive effects of planting methods (bed vs. flat planting), nitrogen levels (100% and 75% of recommended N), and mulching treatments (control, slasher residue mulch, wheat straw @ 3.0 t ha^{-1}, and mango leaves @ 2.5 t ha^{-1}) on zero-till cotton using a split-split plot RCBD with three replications. Results revealed that wheat straw mulch significantly suppressed weed density (12.6 and 18.6 plants m^{-2} at 40 and 60 DAS) and dry biomass (13.4 and 28.7 g m^{-2}), enhanced soil organic matter to 1.01%, and improved available P (9.01 mg kg^{-1}) and K (224 mg kg^{-1}). Wheat straw also accelerated crop phenology, resulting in minimum days to flowering (47.0), boll formation (67.7), and boll opening (97.7). The highest seed cotton yield (1618 kg ha^{-1}), total bolls per plant (31.0), and average boll weight (2.35 g) were recorded under wheat straw mulch. Bed planting combined with recommended nitrogen outperformed flat planting and reduced N levels. Economic analysis showed the highest benefit-cost ratio (1.48) under bed planting with 75% nitrogen and wheat straw mulch. Overall, integrating zero tillage, wheat straw mulching, and optimized nitrogen management provides a sustainable climate-smart strategy for cotton production in arid to semi-arid regions.

Keywords: Conservation agriculture; cotton; nitrogen management; organic mulching; soil health; weed suppression; wheat straw mulch; zero tillage.

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46. Coconut Pulp Valorization in Granola Bars: Nutritional Enhancement and Matrix Optimization for Sustainable Food Systems

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Abstract: Sustainable agrifood transformation requires upcycling nutrient-dense agro-industrial processing residues to support circular bioeconomy practices and reinforce food security. This investigation evaluated the valorization of coconut pulp, an underutilized fiber-dense side stream, as a functional fortification ingredient in granola snack bar matrices. Formulations developed with varying coconut pulp inclusion levels were systematically examined against unfortified control for proximate makeup, gross calorific value, radical-scavenging activity, instrumental color and textural dynamics, FTIR and thermogravimetric (TGA) matrix behavior, and multivariate sensory acceptability. Fortification positively modulated the nutritional density, yielding progressive increases in protein, dietary fat, mineral ash, and gross energy alongside reduced available carbohydrates. Among the evaluated treatments, the S5 formulation was identified as the best-performing condition across nutritional, bioactive, and consumer acceptance metrics. Specifically, S5 achieved a peak crude protein content of 14.89 g/100 g, high mineral ash of 1.80 g/100 g, and an optimized carbohydrate level of 63.39 g/100 g. This treatment demonstrated superior bioactive protection, recording a total phenolic content of 7.96 mg GAE/g and a DPPH radical-scavenging inhibition rate of 43.68%. Instrumental chromaticity confirmed elevated brightness and tonal saturation (L^* = 68.30, a^* = 3.23, b^* = 17.61, ΔE = 5.20), while FTIR and TGA confirmed stable matrix structural cross-linking. Sensory evaluation established highest overall consumer acceptability for S5 at 8.96 out of 9.00. These results demonstrate that upcycling coconut processing by-products provides a viable pathway toward climate-resilient, circular agrifood systems and nutrient-secure confectionery products.

Keywords: Agrifood sustainability; Agro-waste upcycling; By-product valorization; Circular bioeconomy; Coconut pulp; Food security; Functional snacks

47. Developing the Cotton Nursery Transplantation Technology for Wider Area in Punjab

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Abstract: Cotton nursery transplantation is still rarely practiced in Punjab, particularly in Multan and southern districts. Although proven effective in addressing the cotton-wheat sowing conflict, its wider adoption remains limited due to the lack of sustainable technology, mechanized procedures, and standardized methods for large-scale application. A study conducted at the Cotton Research Institute, Multan, evaluated five growth media: clay soil (S), peat moss (P), vermicompost (V), 50% soil + 50% vermicompost (VS), 50% soil + 50% peat moss (PS), and 50% peat moss + 50% vermicompost (PV). Two nursery raising techniques-biodegradable bags and nursery trays-were tested. Results indicated that PV and PS media performed best in terms of germination percentage, speed, and seedling vigour, primarily due to enhanced root length and biomass supported by root-promoting nutrients. Among nursery methods, tray-based transplantation showed superior performance compared to biodegradable bags. Subsequent field trials compared manual transplantation with mechanical transplantation using a cotton nursery transplanter. Although the yield difference between manual and mechanical methods was modest (approximately 2000 kg/ha), mechanized transplantation was significantly faster and more time-efficient, making it a promising option for large-scale adoption.

Keywords: Cotton, Multan, Nursery transplantation, Transplanter

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48. Climate-Smart Wheat Production: Resource-Conserving Strategies for Sustainable and Resilient Cropping Systems

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Abstract: Wheat production in Pakistan is increasingly challenged by climate variability, water scarcity, degrading soil resources, rising production costs and the need to produce more food from limited resources. Climate-smart agronomic management within diversified cropping systems offers an opportunity to improve resource-use efficiency, productivity and resilience while reducing environmental impacts. This paper explores resource-conserving approaches for sustainable wheat production, drawing on research and field experience in cotton-wheat and other systems, conservation agriculture, bed planting, residue and tillage management and improved water management. Experiences from research and farmer-field activities, including work undertaken under the Cereal Systems Initiative for South Asia (CSISA, Pakistan), are considered to highlight the potential of cropping-system management. Particular emphasis is placed on practices that conserve soil and water, improve input-use efficiency, support timely crop establishment and reduce pressure on natural resources. The paper also discusses the importance of crop diversification and environmentally sound agronomic practices for enhancing wheat productivity under changing climatic conditions. The synthesis highlights opportunities for adapting locally appropriate resource-conserving technologies to different cropping environments and for strengthening farmer-oriented research, demonstration and extension. These approaches can contribute to sustainable wheat production, efficient resource use and greater resilience of food production systems in Punjab-Pakistan.

Keywords: climate-smart agriculture; wheat production; conservation agriculture; cropping systems; sustainable agronomy

49. Effects of Climate Variability on Wheat Yield in Pakistan: A Historical Trend Study (2000–2025)

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Abstract: Wheat is the staple food and most important crop in Pakistan. The critical phases of its growth are in February and March that are critically vulnerable, due to warming temperatures and unpredictable rainfall. There is great need to quantify the association of this climate factor and crop production. This study aimed to find the direct effect of the historical variation in temperature and rainfall on national and provincial wheat production in Pakistan over a period of 25 years (2000-2025). The research used a secondary quantitative data analysis method. Historical data of wheat production and area of harvest (2000-2025) was collected from the Ministry of National Food Security & Research, Government of Pakistan. Mean Climate maximum data and precipitation during the wheat growing period (November to April), was collected from the Pakistan Meteorological Department (PMD). Two statistical tests -Correlation coefficients and multiple linear regression analysis were computed using SPSS/Excel to determine statistical link between climatic factors and wheat yield (kg/hectare). The results of statistical analysis demonstrated significant negative correlation ($r = -0.65$, $p < 0.05$) between mean of maximum temperatures at the grain filling stage (February – March) and yield of wheat. According to the regression analysis, with each 1°C increase in spring temperature, leads to reduction in wheat production by 4.5% to 5.2%. On the other hand, moderate and timely precipitation at the vegetative stage was found to have a minimum positive correlation with yield. Late season excess precipitation had a negative effect on yield due to lodging and diseases. The climatic variability, especially terminal heat stress, is one of the main factors influencing wheat yield variability in Pakistan. It also affects nutrition and quality of crop. This study gives a simple, yet evidence-based benchmarking tool for agronomists and farmers. The results clearly call for immediate implementation of simple and scientifically backed adaptation techniques, such as sowing by adjustment of date to avoid spring heat and you can also switch toward officially recommended heat-tolerant wheat varieties.

Keywords: Climate Variability, climate change, wheat yield, smart agriculture Pakistan

50. Phylogenetic and Expression Dynamics of *SlHSP 70.1* Gene in F1 Tomato Hybrids under Heat Stress

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Abstract: Heat shock proteins (HSPs) are stress-responsive molecular chaperones that maintain proper protein folding in response to external and internal stresses. HSP 70 molecular chaperones playing substantial role in plant thermotolerance. Present study was conducted to investigate the expression dynamics of *SlHSP 70* genes in tomato in response to heat stress and to explore evolutionary relationship. Using bioinformatic tools, 21 members of HSP 70 family were identified. Insilico sub cellular localization indicated that most of the members of HSP70 gene family were predicted to be localized in cytoplasm. For evolutionary relationship study, a total of 43 of *SlHSP70* genes were included in the phylogenetic tree showing a hierarchical ancestral relationship of the *HSP 70* genes shared by the members of the kingdom plantae, archea, chromista, Fungai and bacteria. Reverse transcriptase polymerase chain reaction was used to analyze gene expression in leaves of five- week -old tomato seedlings following heat stress treatment (45°C) and control condition(25°C). In F1 hybrid of cross SAMRUDHI ×17903 no expression of SlHSP70.1 gene was observed under control condition but enhanced after heat shock treatment. Desired gene was not expressed among the parents under control and treated condition except for 17903, where upregulation in expression was observed after heat treatment. These expression results, depicting *SlHSP70.1* gene was differentially expressed in parents and hybrids and intensify in F1 hybrid after treatment at 45°C. So, the merging of two genomes by hybridization lead to the remodeling of parental gene expression in hybrids of this cross.

Keywords: Tomato, heat stress, heat shock factors, F1 hybrids

51. Foliar Iodine Application for Tomato Biofortification and Yield Optimization

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Abstract: Iodine (I) is classified as a beneficial micro-element for inducing positive responses in crop plants regarding their proper growth and development. In humans I is served as an essential micronutrient required for healthy life; globally its deficiency approximately affect two billion people, as it is responsible for goiter, mental/ intellectual retardation, stunted growth and other health complications. Due to very low I concentration in agricultural soils, our crops are generally served as poor source of I; but, crop plants especially tomatoes have the ability to accumulate I when administered exogenously. The use of I enriched vegetables served as a tactical substitute to iodized salt, for persons having low sodium diet. Agronomic biofortification of tomato with I, has been therefore proposed as a strategy for prevention of I deficiency worldwide. In present two-year study, greenhouse pot experiments were conducted to quantify the optimal dose of I and the possibility of I foliar spray for agronomic biofortification, in two commercial tomato hybrids. Increasing I concentrations (0, 1, 3, 6 and 9 mM KI/Plant) were administered as foliar treatment and their impact on physiological, yield linked and quality attributes especially I enrichment in tomato fruits were measured. The results of the present study clearly depicted that foliar application with KI induced a considerable increment in tomato fruit I contents, at KI concentrations that also have positive impact on tomato growth and development. These results also propose the functional association of I in crop nutrition and suggesting I translocation through phloem route in tomato. Furthermore, the final I enrichment levels in tomato fruit ranged from a few mg up to 5.27 mg iodine kg−1 fresh fruit weight that are more than sufficient for fulfilling the recommended daily allowance of I (RDA) 150 µg day−1 so, we can claim that I foliar spray even with lowest doses ranging from 1 to 3mM KI solution is enough for biofortification program. All our findings suggest that tomato is particularly an excellent crop for agronomic biofortification of I. In conclusion, the effectiveness, cheapness and easiness of foliar application along with requirement of low dose of I for final enrichment in tomato fruit may favor its wide implementation by farmers, as the most preferred I biofortification approach.

Keywords: Agronomic Biofortification ; Potassium Iodide; Foliar spray; Surfactant; tomato; Hidden Hunger

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52. Autonomous Unmanned Robotic Vehicles (URVs) and their Role in Improving Harvest to Promote Food Security

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Abstract: Unmanned Robotic Vehicles or URVs are autonomous robotic vehicles playing a huge role in the current climate of rapidly developing agricultural techniques. These self-working vehicles are designed to focus on smart sensing, precise navigation and consistent performance in field. URVs are lucrative because in a rising economic crisis where labor is so difficult to hire, maintain and pay for, a one-time investment in these smart machines can ease the workload of farmers significantly and as a result, giving efficient and sustainable crop production in response to increasing rates of food insecurity around the world. URV technology is heavily reliant on aspects of science like precision localizing, multi-sensor perception, intelligent pathway routes and tracking of trajectory. Some vision sensors utilised in URVs include, GNSS/RTK, LiDAR and vision sensors to remain connected with the mapped out trajectory of the vehicle and avoid accidents. However, unpredictable scenarios are to be expected since almost all farmlands are unstructured, prone to sinking, slipping and unexpected inclination caused by climate change and human factors. To counter this concern a super twisting sliding mode control or STSMC in association with multi-criteria parameter optimization metaheuristics like Crayfish Optimization (CPO) are used. They ensure strict adherence to selected path of the vehicle and highly precise field tasks. These smart vehicles can complete tasks like targeted spraying, land cultivation, refined tillage, automated seeding and harvesting. They also waste considerably less fertilizer and pesticides which improves cost saving and harming of vegetative land, thus overall increasing crop yield and countering the rising rates of food insecurity. Some cons of this advancement is its reliance on human maintenance in cases of harsh weather, high replace costs due to expensive materials, manual aid in rerouting if the vehicle loses track of selected path on the farmland and an overall literacy required for the farmers who shall handle the equipment. Keeping the concerns in mind, the future holds attempts at improving fault-tolerant control measures, multi-vehicle collaboration and advanced AI for real-time decision making related to agricultural concerns. These objectives paint a hopeful picture for agricultural advancement which will benefit the infrastructure, the country's GDP and the farmers.

Keywords: Climate crisis, Unmanned automated vehicles, robotics, artificial intelligence, infrastructure, modern agriculture, targeted cultivation.

53. Valorization of Banana Peel for the Development of Snacks

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Abstract: Sustainable food processing by transforming agro-industrial by-products into value-added food products provides an efficient approach to functional food and food waste reduction. This study explored the feasibility of using banana peel, which constitutes about 30–40% of the fruit, as a functional ingredient in the production of snacks, and its performance was compared with the conventional potato (Solanum tuberosum L.) chips. A total of 2 treatments which divided into 12 sub-treatment combinations were created by considering 2 raw materials (banana peel and potato), 2 frying methods (deep frying and air frying), and 3 temperature-time conditions. Deep frying was conducted at 160°C for 2.5 min, 175°C for 3.5 min, and 190°C for 4.5 min, while air frying was performed at 170°C for 12 min, 180°C for 16 min, and 190°C for 20 min using 2–3 g of oil mist per batch. Oil uptake, moisture content, texture, total dietary fiber, total phenolic content, total flavonoid content, DPPH radical scavenging activity, microbiological quality, sensory attributes evaluated by a 9-point hedonic scale, and storage stability for 30 days at ambient conditions were used to evaluate the products. The oil absorption contents of the air-fried samples were considerably lower (4.4 g/100 g) than those of the deep-fried samples (35.7 g/100 g) due to less penetration of oil during convective heat transfer. The ability of banana peel chips to give better nutritional benefits, such as higher levels of dietary fiber and antioxidants, was attributed to their high content of cellulose, hemicellulose, pectin, phenolic acids, and flavonoids, which potato chips lacked. The higher the frying temperature, the greater the degradation of phenolics, flavonoids, and antioxidant activity, since thermal degradation occurred. Air frying kept more phenolics, flavonoids, and antioxidant activity than deep frying due to thermal degradation. Sensory evaluation showed that deep frying at 175°C for 3.5 min and air frying at 180°C for 16 min were the best conditions; air frying the banana peel had the best combination of consumer acceptability, dietary fiber, and antioxidant retention. No microbial spoilage or objectionable flavor or odor was observed after 30 days of storage in a laminated polyethylene pouch. The results proved that banana peel chips could be a good alternative low-fat and fiber-rich functional snack food and can be used as a sustainable utilization of banana processing waste in Pakistan.

Keywords: Banana peel; Air frying; Functional snacks; Dietary fiber; Antioxidant activity; Food waste valorization

54. Design and Development of an Indigenous Low-Cost Footstep Energy Harvesting System for Sustainable Smart Agro-Industrial Applications

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Abstract: Smart and precision agriculture requires reliable power such as for sensor and monitoring devices. Frequent power outages and electricity cost are, however, major problems in Pakistan particularly in rural areas. At the same time, the possibility for recovering mechanical energy from human walking is still very little explored in the agro-industrial and agrarian environments. The main aim of the study is the design and development of an indigenous low-cost footstep energy harvesting system which can be used as an alternative clean energy source for smart farming application. It has been developed a simple gear-and-pinion mechanism, which works by transforming the vertical motion from the footsteps into rotational motion for electricity generation. Fabrication of the system was done using locally available materials, and simplicity, durability, affordability and ease of maintenance were emphasized. The resulting system is a feasible solution for the recovery of mechanical energy that would otherwise be lost due to everyday activities performed by people. Using proper energy storage, the power generated can be used for low power electrical devices such as agricultural sensors, indicator lights, and monitoring devices. This will be a complementary source of clean energy and could decrease reliance on other sources of electricity for some uses. The study emphasizes the potential of indigenous energy harvesting technologies in ensuring sustainable agro-industrial development, renewable energy utilization, resources' efficiency and climate smart agriculture practices.

Keywords: Footstep energy harvesting; Clean energy; Smart farming; Gear-and-pinion mechanism; Renewable energy; Sustainable agriculture.

55. Effect of Irrigation and Nutrient Management on Red Rot Development in Sugarcane

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Abstract: Sugarcane is one of the major crops of Pakistan with it being a 5th largest producer of sugarcane that supports the sugar industry across the country. Despite being a major producer of the crop, the diseases especially red rot, also known as 'cancer of sugarcane,' are proven to be a major hurdle in getting the utmost potential of this crop in terms of both quality and quantity. This disease caused by fungi Colletotrichum falcatum, primarily spreads through the infected setts followed by infected residue and soil but it is observed that inappropriate nutrient management and irrigation scheduling promotes the spread of this disease. During our on-farm trials at Adnan Nauman farm, Saleemabad, we observed the relationship between nutrient management and irrigation scheduling with red rot development and spread in the crop. Our results show that dry conditions, especially during the critical stages like grand growth stage can promote more vigorous spread of the fungi when followed by subsequent irrigation, similarly waterlogged and poor drainage conditions can also indirectly promote the disease spread and intensity. Inappropriate nutrient management can also lead to more vigorous spread of the disease. We made a comparison between the traditional farmer approach and our intervention to understand the above relation both irrigated by central pivot system and fertilized via fertigation. It was observed that under farmers traditional practices the water stress followed by subsequent abundant irrigation helped the disease to spread more vigorously moreover, the excess nitrogen applied at the rate of 6-7 bags of urea per acre accompanied with inadequate supply of Potassium also promoted the infection rate. Under our intervention the results observed showed a clear reduction in the red rot development when crop was timely supplied with irrigation at the required stages with proper amount of potassium and nitrogen via fertigation at the rate of 5-6 bags of urea saving almost 1-2 bags per acre.

Keywords: *Glomerella tucumanensis*; *Colletotrichum falcatum*; irrigation scheduling; nutrient optimization; fertigation; central pivot system

56. Hydrogel-assisted Fertilizer Management Promotes Wheat Growth, Productivity and Drought Adaptation under Limited Water Availability

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Abstract: Climate change-induced drought and poor nutrient utilization pose major challenges to wheat production in arid and semi-arid regions. This study investigated the interactive effects of hydrogel-integrated NPK fertilization and irrigation regimes on wheat growth, physiological performance, yield, and resource-use efficiency. A two-year field experiment was conducted during 2022–2023 and 2023–2024 in Punjab, Pakistan, using a factorial randomized complete block design. The experiment comprised four nutrient–hydrogel treatments, including 75% NPK, 75% NPK + 5 kg ha^{-1} hydrogel, 100% NPK, and 100% NPK + 5 kg ha^{-1} hydrogel, combined with four irrigation regimes: full irrigation, irrigation omission at tillering, irrigation omission at flowering, and irrigation omission at both stages. Hydrogel application with NPK markedly enhanced plant growth, physiological attributes, grain yield, nutrient uptake, water-use efficiency, and nutrient-use efficiency under both adequate and deficit irrigation. The 100% NPK + 5 kg ha^{-1} hydrogel treatment under full irrigation resulted in the greatest growth and grain yield, while under severe water deficit, the same treatment promoted antioxidant activity and improved water-use efficiency. Deficit irrigation enhanced nutrient-use efficiency, with the highest partial factor productivity recorded under 75% NPK + hydrogel. The integration of hydrogel with balanced NPK fertilization therefore improved wheat productivity, resource-use efficiency, and drought resilience, highlighting its potential as a climate-smart approach for sustainable wheat production under water-limited conditions.

Keywords: Abiotic Stress, Drought Resilience, Resource-use Efficiency, Superabsorbent Polymer, Wheat Physiology

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57. Augmented Furrow Sowing of Wheat: A Promising Alternative to Conventional Sowing Methods for Improving Water Use Efficiency Under Deficit Irrigation

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Abstract: Drought is a serious threat for food security globally. Wheat is important staple crop of Pakistan and severely affected by drought at sensitive growth stages. Selection of appropriate sowing method is very important for improving water use efficiency. Traditional sowing methods are not much efficient under limited water condition. There is need to devise new efficient methods of sowing to cope with decreasing irrigation supply to reduce the damaging effects of drought in wheat. Keeping in view the role of improved sowing methods in mitigating the harmful effects of water deficit in wheat, a field experiment was performed to investigate the impact of different sowing methods on yield performance of wheat under limited water conditions at research farm, MNS University of Agriculture, Multan. Research was laid out in RCBD under split plot arrangement. Different sowing methods, including; S1= broadcast, S2= drill sowing and S3= augmented furrow sowing were kept in main plot while different irrigation regimes, including; I1= normal irrigation and I2= skipped irrigation at anthesis stage were kept in sub-plot. All agronomic practices were kept uniform throughout the experiment. Collected data was statistically analyzed by using Fisher's analysis of variance technique. Tukey's honest significance difference (HSD) test was employed to compare different treatment means at 5% level of significance. Different sowing methods and irrigation regimes significantly affected crop growth and development, physiological, agronomic and yield traits in wheat. Among different sowing methods, wheat crop grown by augmented furrow method produced the highest plant height (111 cm), no. of tillers per m2 (427), biological yield (8.96 t ha^{-1}), spike length (11.47 cm), grains per spike (59.62), 1000-grains weight (37.93 g) and grain yield (4.73 t ha^{-1}). Different parameters which were maximum in wheat under normal irrigation were tillers per m2 (354), spike length (11.81 cm), grains per spike (59.47), 1000-grains weight (36.79 g), biological yield (7.82 t ha^{-1}) and grain yield (4.09 t ha^{-1}). Irrigation water use efficiency was recorded 18.63% more under augmented furrow sowing in skipped irrigation at anthesis stage as compared to normal irrigation. Based upon the research findings, it can be concluded that augmented furrow method of sowing is best alternative to conventional sowing methods for improving water use efficiency, growth and yield under drought conditions.

Keywords: Augmented furrow; Broadcast sowing; Drill sowing; Drought; Water deficit; Wheat

58. Regenerative Climate-Smart Practices for Improving Soil Health and Productivity in a Cotton-Wheat Cropping System

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Abstract: Declining soil health and inefficient input use threaten the sustainability and resilience of cotton-wheat systems in arid environments. This study evaluated a combination of no-tillage, legume intercropping and optimized nitrogen management as regenerative, climate-smart practices for improving soil health and system productivity. A two-year field experiment (2024-25) was conducted under bed-and-furrow planting at MNS-University of Agriculture, Multan, Pakistan. Treatments comprised of no-tillage (NT) and conventional tillage (CT), three legume intercrops (Mungbean, Mashbean and Soybean), and recommended nitrogen (NL1) or a 15% reduced nitrogen rate (NL2). Soil health and crop productivity were assessed using selected indicators and yield measurements. Post-harvest soil organic matter in the 0-15 cm layer increased to 1.03% under NT compared with 0.91% under CT, while soil microbial population increased from 5.51×10^5 to 6.14×10^5 CFU under NT. The Cotton + Mungbean-wheat system produced 3908 kg ha-1 wheat grain yield in 2020-2021 compared with 3636 kg ha-1 under sole cotton-wheat, representing a 7.48% increase. Land equivalent ratio under NT reached 1.56 with recommended nitrogen and remained 1.44 with 15% reduced nitrogen in the second year, demonstrating a clear land-use advantage of legume-based diversification. Although the highest seed cotton yield occurred under conventional tillage, the overall findings showed that NT combined with Mungbean intercropping improved soil biological and organic matter status while maintaining productive system performance. Integrating conservation tillage, legumes and optimized nitrogen management therefore offers a practical pathway toward regenerative and climate-smart cotton-wheat production in arid agroecosystems.

Keywords: Climate-smart agriculture; No-tillage; Legume intercropping; Soil health; Cotton-wheat cropping system; Nitrogen optimization

59. Climate Variability Effects on Fenoxaprop-P-Ethyl Efficacy and Selectivity in Wheat

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Abstract: Climate variability can alter the physiological status of crops and weeds and consequently influence the performance and selectivity of herbicides. This study evaluated the individual and interactive effects of temperature and soil moisture on the efficacy of fenoxaprop-p-ethyl against Phalaris minor Retz. and its selectivity in wheat (Triticum aestivum L.), with additional assessment of soil biological responses. A factorial experiment was conducted under controlled environmental conditions using four temperature regimes (10–15, 25–30, 35–40 and 40–45°C) and four soil moisture levels (20–30, 50–60, 70–80 and 100% field capacity). Fenoxaprop-p-ethyl performance was assessed through P. minor biomass reduction, visual injury and mortality, while wheat response was evaluated through phytotoxicity, chlorophyll content, photosynthetic rate and crop recovery. Soil microbial biomass, dehydrogenase and phosphatase activities, and microbial diversity were also determined. Temperature and soil moisture significantly influenced herbicide efficacy, crop response and soil biological properties, with significant temperature × moisture interactions across the measured variables. The most consistent combination of weed control and crop safety occurred under 25–30°C with 70–80% field capacity, where P. minor mortality reached 100%, wheat phytotoxicity was only 8.9%, and crop recovery reached 93.8%. In contrast, temperature extremes substantially reduced crop physiological performance and increased phytotoxicity, with wheat injury reaching 24.9% under 40–45°C and severe moisture stress. Soil biological activity was also strongly influenced by the environmental regime; microbial biomass, dehydrogenase and phosphatase activities were highest under favorable temperature and moisture conditions and markedly reduced under extreme heat combined with moisture deficit. Interestingly, extreme heat with adequate moisture produced high visual injury and biomass reduction but did not result in equivalent mortality, indicating that severe herbicide injury does not necessarily translate into complete weed control under environmental stress. Overall, the findings demonstrate that climate variability can modify the efficacy and selectivity of fenoxaprop-p-ethyl and influence the biological condition of the soil. Appropriate consideration of temperature and soil moisture at herbicide application may therefore improve weed-control reliability, crop safety and sustainability of wheat production under increasingly variable climatic conditions.

Keywords: Climate variability; *Phalaris minor*; Fenoxaprop-P-ethyl; herbicide efficacy; selectivity; temperature stress; soil moisture; Wheat

60. Central Pivot Irrigation: A Sustainable Approach to Agricultural Water Management

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Abstract: Ensuring freshwater availability with supply sufficient for socio economic development is very important for human health and productivity. Irrigation amount is one of the most important factors in agricultural water management. A central pivot system is a movable pipe structure that rotates around a central pivot point while connected to a water supply. Central pivot sprinkler systems are popular because of their high efficiency, ability to irrigate large and uneven fields, reduced labour requirements, and time savings. The system moves through the field by electrically powered wheels, while flow rates increase toward the outer end of the pivot because the end of the pivot travels faster. A comparative assessment was conducted for maize at Nishat Agriculture Farm, Hafizabad, to evaluate the potential difference between conventional and central pivot irrigation on a per-acre basis. Water application, irrigation time, labour requirements, and water use efficiency were compared under similar field conditions. Conventional irrigation was estimated to require approximately 1,500 m^3 of water per acre per irrigation, whereas central pivot irrigation was estimated to apply approximately 900 m^3 per acre, indicating a potential water saving of approximately 40%. The central pivot system also provided potential for more uniform water distribution. These results indicate that central pivot irrigation can improve water use efficiency in maize production and reduce unnecessary water application. Despite its high efficiency, it also faces challenges including high initial investment, energy requirements, maintenance expenses, and uneven irrigation performance under unsuitable conditions. Central pivot irrigation improves water use, saves labour and time, and reduces water wastage. Central pivot irrigation improves water efficiency under climate change. In Pakistan, its future is promising due to water scarcity, especially when integrated with precision technologies for sustainable and climate-resilient agriculture.

Keywords: Central pivot irrigation; Maize; Irrigation efficiency; Water-use efficiency; Water conservation; Sustainable irrigation; Precision irrigation; Agricultural water management

61. Protecting Pollinators and Natural Enemies While Managing Insect Pests in a Warming Climate

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Abstract: The pollinators and natural enemies are important ecosystem services such as pollinators of crops and natural enemies of insect pests, but both groups are facing increasing threats due to climate change. Increase in temperature, heat wave, change in the occurrence of flowering periods and droughts interfere with insect development, foraging, survival, and can lead to phenological mismatch between beneficial insects, their hosts and flowering crops. Intense pressure from insecticide application, which can be increased when warmer temperatures promote quicker pest development and higher numbers of generations per season. Furthermore, an increase in temperature may cause insecticide toxicities to change and increase the susceptibility of non-target species to sublethal exposure. This paper summarizes recent trends on how climate warming and pest management practices affect pollinators and natural enemies and presents a set of strategies that can help to preserve pollinators in climate-smart Integrated Pest Management (IPM). These include changing from broad-spectrum insecticides to selective and low-risk alternatives, timing treatments to reduce exposure of beneficial insects and applying biopesticides and monitoring/trapping with semiochemicals as targeted alternatives. Flowering field margins, cover crops and shaded refuges as well as habitat management provide food, shelter, and thermal buffering during extreme heat. Use of thermotolerant parasitoids, predators and entomopathogens further enhances biological control in changing times. We conclude that protecting beneficial insects is essential for achieving sustainable pest management in a warming climate and that a combination of conservation, farmer training and supportive pesticide policies can ensure both crop protection and pollination services while simultaneously ensuring yield stability and agro ecosystems resilience.

Keywords: Climate change, Pollinators, Natural enemies, IPM, Selective insecticides, Conservation biological control

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62. Climate-Smart Integrated Pest Management: A Framework for Building Resilient Crop Protection Systems under Changing Climates

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Abstract: Climate change is affecting pest management worldwide by altering developmental rates, thereby increasing the number of generations per season as well as the geographic spread of both invasive and migratory species. At the same time, heat, drought and unpredictable rainfall patterns undermine the efficacy of traditional pest control measures putting food security, particularly for smallholder farmers in developing countries, at risk. This paper proposes a framework for climate-smart integrated pest management (IPM) by contextualizing principles of IPM in dynamic environmental conditions. The framework focuses on (i) climate-informed surveillance and forecasting through the use of weather data, degree-day models and species distribution modelling to predict outbreaks; (ii) dynamic economic thresholds that take into account temperature variation and its effect on pest development and crop susceptibility; (iii) climate-resilient pest control tactics including thermotolerant biocontrol agents, semiochemicals-based monitoring and trapping, habitat conservation for natural enemies and climate-adapted resistant crop varieties; and (iv) innovative digital technologies such as remote sensing, drones and digital advisory services for timely decision-making. Evidence from the literature shows that these elements when deployed together reduce reliance on synthetic insecticides, mitigate insecticide resistance, conserve pollinators and beneficial insects while enhancing yield stability under changing climates. Key challenges identified include lack of access to technology, lack of local ecological knowledge and inadequate extension services. It is concluded that enhancing predictive capacity, farmer training and supportive policies will promote the adoption of climate-smart IPM practices to ensure sustainable production systems.

Keywords: Climate change, Climate-smart IPM, Pest forecasting, Biological control, Semiochemicals, Resilience

63. Silicon Improves Photosynthesis and Nutrient Accumulation in Sugarcane under Combined Water and Potassium Deficit

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Abstract: Water deficit and potassium (K) deficiency often occur together in tropical sandy soils and limit sugarcane productivity by impairing photosynthesis and nutrient acquisition. Silicon (Si) mitigates abiotic stresses, but whether it sustains photosynthetic and nutritional performance under both stresses combined is unclear. Plant cane was grown in a greenhouse in a 4×2 factorial design with four replications: control, water deficit (WD), K deficiency (−K) and combined stress (WD-K), without or with Si (8 kg ha^{-1} via fertigation as colloidal nanosilica). Stress reduced photosynthetic and nutritional traits. Whereas, Si application enhanced net photosynthesis, stomatal conductance and transpiration across growth conditions, and increased chlorophyll a, chlorophyll b and carotenoid contents and the maximum quantum efficiency of PSII (Fv/Fm). Besides, K deficiency reduced leaf K accumulation by 75–85%, confirming the imposed stress. Si increased K and Fe accumulation in green leaves, even under K deficiency, while maintaining the accumulation of Ca, Mg, Zn, Mn and Cu. Si also reduced K, Ca, Mg, Fe, Zn and Cu losses in senescent leaves by decreasing dry leaf mass. These responses were accompanied by greater green leaf dry mass and leaf area, which increased with Si by 15% in the control, 33% in WD, 64% in −K and 28% in WD-K. Overall, Si fertigation mitigated the effects of water deficit and K deficiency, individually and combined, by improving photosynthetic performance and nutrient accumulation and maintaining green leaf area. These findings highlight Si fertigation as a promising strategy for sugarcane in water- and K-limited environments.

Keywords: Nanosilica; Fertigation; Gas exchange; Nutrient accumulation; *Saccharum* spp.

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64. Plant Growth Regulators Improved Photosynthesis, Osmotic Adjustment, and Grain Yield in Late-sown Wheat under Natural Saline Conditions

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Abstract: Wheat often faces salt stress and delayed sowing; in real field conditions, these two events often occur simultaneously, causing severe consequences for reactive oxygen species (ROS) accumulation, antioxidant machinery, photosynthesis, and ultimately yield. To address these issues, a two-year field trial was done and it comprised of following factors, a) timely sown under normal conditions (NS) and late sowing under normal conditions (LS) b) timely sown on saline conditions (SS) and late sown under saline conditions (LS+SS) c) foliar application of plant growth promoters (hydrogen peroxide (H_2O_2), salicylic acid (SA), thiourea (TU), water (H_2O), control (no spray) firstly to evaluate the effect of plant growth promoters (PGPRs) on osmolytes metabolism, ROS homeostasis, antioxidant responses, photosynthesis and yield under SS, late-sowing (LS) and their combined treatments (LS+SS). Data revealed that under stress conditions, especially SS+LS, plants increased the synthesis of osmolytes and antioxidants, enhanced heat dissipation, and showed strict control over stomatal regulation and gas exchange; these mechanisms were adjusted to cope with the stresses. In addition, SS+LS stress, followed by SS and LS stress, severely reduced grain yield and gas exchange attributes. However, foliar application of PGRPs, TU, followed by SA, H_2O_2, H_2O, and control, improved gas exchange attributes, osmolytes, antioxidants, and yield parameters. So, foliar PGPR treatments, particularly TU, offer a potential strategy to improve wheat performance in saline environments where timely sowing is difficult.

Keywords: Late-Sown; Salinity Stress; Plant Growth Promoters; Osmolytes; Reactive Oxygen Species; Antioxidants, Grain Yield

65. Improving the Productivity of Drought Stressed Fennel (*Foeniculum vulgare*) through Foliar Osmoprotectants

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Abstracts: Fennel **(***Foeniculum vulgare***)** is a highly versatile, medicinal and culturally significant plant. Drought stress significantly reduces overall growth, grain yield and quality of fennel (*Foeniculum vulgare*). This study was investigated to evaluate effectiveness of osmoprotectants against drought stress in fennel under Bahawalpur conditions. Different foliar osmoprotectants (F_0 Foliar spray of water, F_1 Foliar application of 2% potassium, F_2 Foliar application of 2% calcium, F_3 Foliar application of 20 mg/L proline and F_4 Foliar application of 20 mg/L glycine betaine) were applied on fennel at different level of drought stress (D_0 Application of 3 irrigations at vegetative, flowering and seed formation, D_1 Skipping of 1 irrigation at vegetative stage, D_2 Skipping of 1 irrigation at flowering stage and D_3 Skipping of 1 irrigation at seed formation stage). Application of odmoprotectants showed significant effect on growth and yield behaviour of fennel crop. Higher yield was recorded with foliar application of 2% K under drought stress at vegetative stage. The possible reason to enhance the yield of fennel is potassium (K) application. The finding of this study may be helpful for improving the yield and quality of fennel under drought and water limited condition in changing scenario of climate.

Keywords: Fennel (*Foeniculum vulgare*), osmoprotectants, drought stress, yield

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66. Influence of Aloe Vera Extract and Sodium Nitroprusside on Morphological and Physiological Responses of Vinca under Water Stress

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Abstract: Vinca (*Catharanthus roseus*) is an important ornamental flowering plant valued for its attractive blooms, adaptability, and landscape applications. However, water deficit is one of the major environmental constraints that adversely affect its growth, flowering, and overall ornamental quality. The present study was conducted to evaluate the effects of Aloe vera extract (AVE) and Sodium Nitroprusside (SNP) on the growth and flowering performance of Vinca under water-deficit conditions. Two independent pot experiments were carried out at the Horticulture Propagation Unit, Muhammad Nawaz Sharif University of Agriculture, Multan, during 2025 under a Completely Randomized Design (CRD) with a two-factor factorial arrangement and three replications. Two irrigation regimes were maintained: 100% field capacity (well-watered control) and 60% field capacity (drought stress). In Experiment I (Optimization of aloe vera extract and sodium nitroprusside dose). In Experiment II (Evaluation of combined optimized doses of aloe vera extract and sodium nitroprusside). Two foliar applications were made at one week interval. In first experiment data of morphological attributes (number of flowers, flower fresh weight, flower dry weight, shoot length, root length, shoot fresh weight, shoot dry weight, root fresh weight and root dry weight) and in second experiment data of morphological, physiological (relative water content, chlorophyll a, chlorophyll b and carotenoids) and biochemical (membrane stability index, catalase, peroxidase, superoxide dismutase and hydrogen peroxide) parameters were recorded after one week of second foliar application. It was concluded that under water stress, combined optimized doses (AVE+SNP) significantly improved number of flowers (64.4%), flowers fresh weight (109.4%), flowers dry weight (31.3%), shoot length (88.3%), root length (69.3%), shoot fresh weight (83.2), shoot dry weight (80.4%), root fresh weight (51.0%), root dry weight (103.8%), catalase (145.6%), peroxidase(39.3%), superoxide dismutase (122.2%), hydrogen peroxide (50.9%), membrane stability index (60.8%), chlorophyll a (63.8%), chlorophyll b (76.4%) and carotenoid (23.5%)

Keywords: Aloe vera extract; *Catharanthus roseus*; drought stress; field capacity; seasonal flowering

67. Role of Strigolactones in Plant Responses to Drought Stress: Physiological and Molecular Mechanisms

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Abstract: Drought is one of the most critical environmental constraints affecting plant growth, productivity, and agricultural sustainability, with its frequency and severity expected to increase under climate change. Understanding the signaling mechanisms that coordinate plant growth and stress responses is therefore essential for developing effective strategies for drought-prone agricultural systems. Strigolactones (SLs), carotenoid-derived phytohormones and rhizospheric signaling molecules, have emerged as important regulators of plant development and adaptation to environmental stresses. Increasing evidence indicates that SLs play a multifaceted role in plant responses to drought by coordinating root system architecture, shoot growth, stomatal regulation, photosynthetic activity, and cellular redox homeostasis. Under water deficit, SL signaling is closely interconnected with abscisic acid, auxin, cytokinins, ethylene, and other regulatory pathways, enabling plants to balance growth and resource allocation with stress responses. In addition, SLs contribute to the regulation of reactive oxygen species (ROS) production and scavenging, thereby supporting antioxidant defense and protecting cellular structures from oxidative damage. At the soil–plant interface, SLs also influence arbuscular mycorrhizal associations and rhizosphere interactions, which may enhance water and nutrient acquisition under drought conditions. This presentation synthesizes current knowledge of SL biosynthesis and signaling in drought-stressed plants, with particular emphasis on the physiological and molecular mechanisms underlying SL-mediated regulation of water relations, photosynthesis, root development, hormonal crosstalk, and redox homeostasis. Finally, the potential of SLs and their synthetic analogs as promising tools for improving plant performance under water-limited conditions and contributing to climate-smart agricultural systems will be discussed.

68. Developing the Cotton Nursery Transplantation Technology for Wider Area in Punjab

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Abstract: Cotton nursery transplantation is still rarely practiced in Punjab, particularly in Multan and southern districts. Although proven effective in addressing the cotton–wheat sowing conflict, its wider adoption remains limited due to the lack of sustainable technology, mechanized procedures, and standardized methods for large-scale application. A study conducted at the Cotton Research Institute, Multan, evaluated five growth media: clay soil (S), peat moss (P), vermicompost (V), 50% soil + 50% vermicompost (VS), 50% soil + 50% peat moss (PS), and 50% peat moss + 50% vermicompost (PV). Two nursery raising techniques; biodegradable bags and nursery trays, were tested. Results indicated that PV and PS media performed best in terms of germination percentage, speed, and seedling vigour, primarily due to enhanced root length and biomass supported by root-promoting nutrients. Among nursery methods, tray-based transplantation showed superior performance compared to biodegradable bags. Subsequent field trials compared manual transplantation with mechanical transplantation using a cotton nursery transplanter. Although the yield difference between manual and mechanical methods was modest (approximately 2000 kg/ha), mechanized transplantation was significantly faster and more time-efficient, making it a promising option for large-scale adoption.

Keywords: Cotton, Growth media, Transplantation, Precision agriculture

69. Phenolic compounds stability and antioxidant capacity of cookies prepared from colored wheat by changing baking conditions and dough formulations

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Abstract: Colored wheat contains naturally occurring bioactive compounds like phenolics, anthocyanins and flavonoids as well as carotenoids. It has great potential as a raw material in functional bakery products. These phenolic compounds are heat sensitive and are lost during extreme baking conditions. To preserve them various formulations of the dough with different baking conditions were practiced. The current research aims to assess the nutritional and phytochemical properties of colored wheat varieties and to explore their potential in the manufacturing of cookies with better retention of phenolic compounds. Eight colored wheat varieties named T1(AR-26), T2(AR-5), T3(BLA-2), T4(BLA-7), T5(BLA-4), T6(BLA-6), T7(BLA-3) and T8(WVT-1219). One control (simple durum wheat) variety T0 was taken. Each colored wheat variety was treated with 0.25%, 0.5% and 0.75% citric acid in its dough formulation. Baking temperature was different for each dough formulation as 140 ˚C, 150 ˚C and 160 ˚C. All wheat varieties were analyzed for proximate analysis, total phenolic content (TPC), antioxidant activity and Vitamin A content. Different wheat cultivars were then selected to prepare cookies of different formulations, including different quantities of citric acid and baking methods to assess the nutritional and bioactive compounds content after baking. The obtained data was subjected to statistical analysis and the results showed that T4 showed higher concentration of total phenolic content as 156.29 mg GAE/100 g followed by T7 and T6 as 145.17 and 140.24 mg GAE/100 g respectively. Antioxidants were higher in T8 as 68.83 % of inhibition followed by T0 and T7 as 67.37 and 66.95 % of inhibition respectively. Vitamin A was higher in T6 as 4.56 µg/100 g followed by T8 and T4 as 4.15 and 3.65 µg/100 g respectively. Comparison of these results with the results obtained from the analysis of product told that T7 shows higher concentrations of total phenolic content as 187.76 mg GAE/100 g and T6 shows higher concentrations of antioxidants as well as vitamin A in a range of 63.80 % of inhibition and 2.79 µg/100 g. According to sensory evaluation, T1 becomes most preferred followed by T3 for color, appearance, aroma, taste, texture, consistency, after taste and overall acceptability. The highest phytochemical enrichment was achieved in T7, the highest vitamin A content and antioxidant capacity was found in T6, and the highest sensory acceptance was in T1. Finally, it can be concluded that colored wheat T6 and T7 had good potential in improving functional & nutritional properties of cookies

Keywords: Anthocyanins; Antioxidant activity; Cookies; Colored wheat; Flavonoids; Functional foods; Phenolic compounds; Sensory evaluation; Vitamin A

70. Production and Characterization of Plant-based Milk from Guar Beans (*Cyamopsis tetragonoloba*)

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Abstract: Guar bean is rich in protein, dietary fiber, galactomannan gum, minerals and bioactive compounds that can be used to produce a nutritious plant-based milk. The guar beans were soaked for five times: 0, 6, 12, 24 and 48 h and their guar milk was prepared in this study. The physicochemical, nutritional, mineral, antioxidant, microbial, rheological and sensory characteristics after soaking for different duration were analyzed. As the soaking time increased, the pH decreased significantly ($p<0.05$) and the crude protein percentage increased from 22.94% to 5.24%, while the titratable acidity, total soluble solids and specific gravity (1.636 to 0.681 mPa·s) were respectively decreased significantly ($p<0.05$). Mineral contents including zinc, iron, calcium, sodium and potassium decreased during soaking, while the phenolics increased by numbers. Similar to the DPPH antioxidant activity, the activity also reduced significantly from 83.45% to 27.97%. Increased microbial load and decreased product quality were obtained with increase in soaking time. Moderate soaking (6h) gave the most acceptable guar milk based on sensory evaluation, while longer soaking treatments resulted in better colour, unsatisfactory taste and mouthfeel as well as less beany flavour. The results showed that the soaking time had a significant effect on the nutritional, physicochemical, antioxidant, microbial, rheological and sensory properties of guar milk. Moderate soaking resulted in the best overall quality and it may be useful to consumer health in the development of acceptable, nutritious and functional guar-based milk beverages. This supports commercialization.

Keywords: Cyamopsis tetragonoloba; Guar bean; Galactomannan; Soaking time; Plant-based milk alternative

71. Climate-Smart Wheat Monitoring with Sentinel-2 Vegetation Indices: Evidence from Khanewal District, Pakistan

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Abstract: In Pakistan, wheat has a pivotal role in food security, and the traditional way of doing crop monitoring is still largely field scouting, with the drawbacks of being slow and often too late for timely management decisions. Vegetation indices derived from satellite data can provide an alternative approach to assessing crop health, moisture status and climate-sensitive canopy development. This study aimed to quantify wheat crop health in a field at District Khanewal, Punjab, based on Sentinel-2 data and the crop monitoring platform Land Information and Management System (LIMS). Six indices (NDVI, NDMI, SAVI, MSAVI, NDRE and ReCI) were calculated for each wheat growth stage, and the 2023-24 season was compared with the 2024-25 season. The 2023-24 and 2024-25 crops had similar peak NDVI values (0.38 and 0.39, respectively), but the 2024-25 peak occurred earlier and was sustained for a longer period. There were more fluctuations in rainfall in the December-January period in 2023-24, with NDMI showing a more pronounced trend of staying around 0.23-0.30 through the months. Overall, these patterns suggested that improved moisture availability resulted in better canopy development in 2024-25. SAVI and MSAVI were helpful for minimizing soil background effects in early growth, while NDRE and ReCI indicated chlorophyll-related status. The findings show that freely available Sentinel-2 data can be exploited during climate variability to aid decisions on irrigation and fertilizer management.

Keywords: Digital agriculture; vegetation indices; wheat; precision agriculture; climate-smart agriculture

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72. Integrating Remote Sensing and Artificial Intelligence for Climate-Smart Agriculture and Drought Monitoring

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Abstract: Climate change is increasingly affecting agricultural productivity through rising temperatures, irregular rainfall, and frequent drought events, particularly in water-limited regions. Timely identification of crop water stress and accurate assessment of drought conditions are therefore essential for sustainable and climate-smart agricultural management. Conventional field-based monitoring methods provide valuable information but are often labor-intensive, time-consuming, and limited in spatial coverage. Recent advances in digital technologies, remote sensing, and artificial intelligence (AI) provide opportunities for rapid and large-scale monitoring of agricultural systems. This study proposes an integrated framework combining satellite remote sensing data with AI-based approaches for monitoring drought stress and assessing crop conditions. Remote sensing indicators such as Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Land Surface Temperature (LST), and vegetation or moisture-related indices can be used to characterize crop health, vegetation dynamics, and water stress. These remotely sensed variables can be integrated with meteorological and field observations to develop AI-based models for drought detection and crop stress assessment. Machine learning techniques, including Random Forest, Support Vector Machine, and Artificial Neural Networks, can be evaluated for their ability to identify spatial and temporal patterns of agricultural drought. The proposed approach can support early detection of crop stress, spatial mapping of vulnerable agricultural areas, and improved decision-making regarding irrigation and crop management. Integration of digital technologies with remote sensing and AI can reduce dependence on extensive field observations while improving the efficiency and scalability of agricultural monitoring. Such technology-driven approaches have significant potential for strengthening climate resilience, improving water-use management, and supporting sustainable agricultural productivity under changing climatic conditions.

Keywords: Artificial intelligence; climate-smart agriculture; drought monitoring; remote sensing; machine learning

73. Climate-Resilient Maize Production through Efficient Irrigation and Sustainable Soil Management under Water Stress

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Abstract: Climate change is increasing water scarcity, temperature stress, and uncertainty in agricultural production, particularly in semi-arid regions of Pakistan. Maize production is highly dependent on adequate water availability, making efficient irrigation and sustainable soil management important approaches for improving climate resilience. This study evaluates the response of maize varieties to different irrigation regimes and soil management treatments under semi-arid conditions of Multan, Punjab, Pakistan. The experiment consists of two maize varieties, two irrigation regimes, four soil management treatments, and three replications. The study focuses on crop growth, yield-related characteristics, water use efficiency, and soil health indicators. Efficient irrigation combined with suitable soil amendments is expected to improve soil moisture retention, reduce water losses, and enhance maize productivity under water-limited conditions. The findings may provide practical information for developing climate-resilient and water efficient maize production strategies. This research can contribute to sustainable agricultural water management and adaptation to increasing climate variability in semi-arid regions.

Keywords: Climate resilience, water management, maize, irrigation, soil management, water-use efficiency, climate change

74. Phenotypic and Quality Profiling of Durum Wheat Germplasm for Improved Pasta Quality

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Abstract: Durum wheat (Triticum durum) is one of the most important and nutritive cereal of wheat belongs to family poaceae. Durum wheat kernel is hard, vitreous, yellow colored and is mainly utilized for manufacturing pasta. Pasta is healthy and nutritious product having different shapes and sizes. Pasta consumption as food is increasing day by day. For characterization of durum wheat based on pasta making potential, it was evaluated for physical and compositional analysis. The dough characteristics of durum wheat were examined on mixograph which was illustrated as weakening of dough, stability of dough, time for dough development and water absorption of the flour. Afterwards, pasta was prepared from durum wheat germplasms and physicochemical and quality parameters were determined. Physicochemical analysis was based on color, cooked weight, cooking loss and firmness of pasta. On the other hand, quality characteristics of pasta were appearance, elasticity, stickiness and palatability. Color was carried out to check the darkness and brightness level of durum wheat varieties. The variety D7 was best for pasta color (7.06±0.98), D2 was on top for pasta cooking loss (2.87±0.24) and D2 was acceptable for pasta firmness (292.66±3.51). The stickiness of pasta exhibited non-significant ($p>0.05$) result and cooked weight of pasta's was highly significant. The durum wheat varieties D2, D5 and D7 were best for preparation of pasta regarding pasta making potential.

Keywords: Durum wheat; Mixograph; Cooked weight; Color; Cooking loss; Quality parameters

75. Integrating Microbes with Organic and Inorganic Amendments for Improving Soil Health, Nutrient Uptake, and Maize Productivity under Salinity Stress

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Abstract: Salinity is projected to affect up to 50% of irrigated lands by 2050, posing a major threat to global food security by decreasing the output of various crops. This study aimed to assess the integrated efficacy of biochar (BC), vermicompost (VC), elemental sulfur (ES), and salt-tolerant plant growth-promoting rhizobacteria (MC), in reclaiming saline soils and boosting maize growth in salt stress conditions. A pot experiment was carried out following a completely randomized design with 17 treatments and three replications. Artificial salinity (EC, 9 dS m^{-1}) was induced using a combination of salts to evaluate its effects on maize growth and soil characteristics in a pot experiment. The application of BC (1%), VC (2%), and ES (0.2%) were tested, with MC. The results demonstrated that salinity stress significantly reduced agronomic (55%) and physiological (60%) traits of maize compared to the non-saline control. However, the application of soil amendments significantly mitigated the adverse effects of salinity. Under saline conditions, although individual application of each amendment was effective, their combined applications demonstrated greater improvements, showing substantial increase in agronomic (upto 53%) and physiological (upto 59%) attributes over the respective unamended saline control. Furthermore, the integrated application of MC, BC, VC, and ES also improved plant nutrient uptake, soil fertility and other biochemical attributes by enhancing plant growth, physiological efficiency and stress tolerance, suggesting that their integrated use is a sustainable and effective strategy for enhancing maize productivity. The outcomes of this study are helpful in developing a strategy using sustainable and cost-effective soil amendments that enhance maize productivity under salinity stress, while improving long-term soil health and agricultural sustainability.

Keywords: Salt stress; Maize; PGPR; Biochar; Vermicompost; Soil fertility

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76. Appraising Herbicide Performance in Wheat and Residues in Soil and Crop Produce

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Abstract: The management of weeds in winter wheat is a complex task since crops are infested by diverse weed species. Pre-emergence herbicides can be applied to control weeds during the early stages of crop growth. Nevertheless, they require critical moisture regime at the time of application and have a very limited application window and a relatively restricted control spectrum which means that additional weed control might be needed in the later growth stages of crop. Post emergence herbicide application offers control of the remaining as well as the late emerging flushes of weeds and hence can minimize the accumulation of weed seed bank. However, the continuous application of herbicides can create herbicide persistence in soil and also residues in crop produce. Experiment to evaluate herbicide persistence in soil and residues in crop produce was conducted during winter, 2022-23 in the experiential field of MNS University of Agriculture Multan. Plots of wheat were sprayed with one pre-emergence (Pendimethalin at 1137 g a.i ha-1, and six post-emergence herbicides (Bromoxynil+MCPA at 450 g a.i ha-1, Florasulam+MCPA+Mesosulfuron at 112.5 g a.i ha-1, Iodo+Mesosulfuron at 14.4 g a.i ha-1, Sulfosulfuron at 19 g a.i ha-1, Fluroxypyr+MCPA at 39.37 g a.i ha-1 and Pinoxaden at 41.25 g a.i ha-1. Post-emergence application of Florasulam+MCPA+Mesosulfuron was effective in reducing weed biomass as compared to weedy check plots and also enhanced yield (grain yield, 1000-grains weight and grains per spike) and growth attributes (plant height, crop biomass). Grain yield in this treatment was 61% higher than the weedy check plots. All the applied herbicides persisted for different time spans at 0-15, 15-30 and 30-45 cm soil depths. Pendimethalin was the only herbicide that persisted up to 90 days. Herbicide residues in wheat grains and straw at harvest were below their maximum residue levels. So, all the tested herbicides were found safe to control weeds in winter wheat crop. Further, the present research work found that growth and yield of wheat can be enhancd through proper management of weeds.

Keywords: Chemical weed control; Herbicide persistence; Herbicide residues; Irrigated wheat; Weed infestation; Weed inflited losses

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77. Millets: The Future Smart Crops for a Changing Climate

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Abstract: Current crop production lacks much needed diversity in agro-ecosystems. Food security paradigm needs to be augmented with sustainability and nutritional security to combat malnutrition and challenges associated with climate change. Revival of the lost cereals or introduction of new climate resilient crops would be the key in this regard. Millets with their unique agronomic characteristics and superior nutritional profile are regarded as versatile crops for climate smart agriculture in the backdrop of declining agricultural productivity, burgeoning population, depleting natural resource base and ever-increasing cost of agricultural inputs. Moreover, millets are not just versatile crops but also reflect food cultures and rich agricultural practices and heritage in which answer to new age crises is embedded. Exhaustive depletion of land and water resources and their deteriorating quality has left a little room for vertical expansion in crop production. This warrants the need to improve yield per unit area, and devise strategies for crop production even under stressful environments with limited resources. Proso millet (*Panicum miliaceum* L.), locally known as "Cheena" and Foxtail millet (*Setria italica* (L.) P. Beauv), locally known as "Kangni", with their unique ability to grow in hot dry arid climates on marginal lands can be promising crops to cope with declining water availability, rising atmospheric CO2 and temperature. Moreover, evaluation of crops for food and forage purposes in new growing environments/ecologies requires critical appraisal of their establishment, including morpho-physiological attributes, dry matter, seed yield and nutritional profiling. Here at MNS University of Agriculture, Multan, we are working on agronomic interventions for successful production of these crops for diversification, nutritional security, climate smart agriculture and postharvest value addition.

Keywords: climate smart agriculture; crops for hostile environments; dry land farming; Irrigated wheat; food and nutritional security; neglected and underutilized crops

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78. Agronomic Performance and Yield-Related Traits of Diverse Proso Millet (*Panicum Miliaceum* L.) Genotypes

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Abstract: A field trial was conducted to evaluate the performance of 345 proso millet genotypes under field conditions. Better crop emergence and stand establishment was noticed for 97 genotypes. However, 27 genotypes were poor performers. No emergence was recorded for 23 genotypes. Genotype IPM-2801 took 8 days to emerge, while most other genotypes completed emergence in 7 days. Plants per unit area ranged from as low as 5 plants m-2 to as high as 110 plants m-2. Plant height (cm) of 69 genotypes was better than rest of the genotypes sown in the field. Overall plant height of proso millet ranged from 28.67 cm to 98.67 cm, which showed considerable variation and varied from 98.67 cm (IPM-2107) to 28.67 cm (IPM-2847), reflecting differences in genetic background and suitability for biomass vs. grain production. Tillers per plant ranged from 2-20, with IPM-2840 (2 tillers per plant) and IPM-2839 (20.33 tillers per plant). Number of leaves ranged from 8 to 97 leaves per plant. IPM-1609 had 97 leaves and IPM-1603 had almost 78 leaves, while plants of IPM-2643 had only 8 leaves. IPM-363 showed exceptionally long (39 cm) and IPM-2768 had short panicles (6 cm), respectively. IPM-2760 (165 g), IPM-2625 (129 g), and IPM-2116 (160 g) were best performers regarding seed output. The time to flowering in proso millet varied among genotypes, ranging between 30 to 45 days after emergence. Genotype IPM-2818 exhibited the longest duration (45 DAE), suggesting a relatively late flowering tendency, while IPM-2842 flowered earliest at 30 DAE. This variation highlights genetic diversity in flowering behavior, which can be useful for selecting early or late maturing lines based on agro-climatic requirements. No flowering was observed for proso millet genotypes, viz. IPM-2638, IPM-2153, IPM-1602, ipm1608, IPM-2205, IPM-1563, IPM-2162, 1562, IPM-1606, IPM-2246, IPM-1600 IPM-2225, IPM-1576, IPM-2267, IPM-2188, IPM-2734. The genotype IPM-2618 exhibited the highest number of seeds per panicle (1200), while IPM-1597 recorded the lowest (62), showing wide genetic variability. This variation highlights the potential for selecting high-yielding genotypes. Harvest Index ranged from 1 to 68%. Genotypes like IPM 2842, 2848, 2855, 2239, 2141, 2760, 1604, 2052 and 2845 scored harvest indices of above 50%.

Keywords: genetic diversity; field appraisal; future smart food crops; promising genotypes; trait variation; neglected and underutilized crops

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79. Wheat-White Lupin Intercropping for Crop Diversification, Climate Resilience, Weed Suppression, Food and Feed Security

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Abstract: Cereal-legume intercropping is an environmentally friendly way of ecological intensification for agricultural production. A study was conducted at MNS University of Agriculture, Multan, Pakistan over Winter 2024-2025 to assess the effectiveness of intercropping wheat (*Triticum aestivum* L.) with white lupin (*Lupinus albus* L.) under irrigated conditions. In this study, an attempt was made to appraise the planting geometries to enhance crop diversity, efficient use of resources, weed control, and food/feed security. There were seven treatments, viz. wheat monoculture (T1), lupin monoculture (T2), and five different row ratios of wheat-white lupin intercrops (T3-T7). Sole cropping gave the highest individual yields of wheat (5024.43 kg ha-1) and lupin (1165.04 kg ha-1) and the highest wheat plant height (96.44 cm) and harvest index (43.95%). But, intercropping improved total productivity and land efficiency greatly. Combinations as the T4 [Wheat (20 cm spaced 10 crop rows: 2 m) + lupin (40 cm spaced 5 crop rows: 2 m)] having optimal geometry with wheat grain yield of 4851.17 kg ha-1 (a minor reduction of only ~3.5% when compared with sole wheat) and lupin seed yield of 811.04 kg ha-1. Maximum biological yield (12,307.5 kg ha-1) occurred in T3 [Wheat (15 cm spaced 20 crop rows: 3 m) + lupin (25 cm spaced 4 crop rows: 1 m)], followed by T4 (12,134.4 kg ha-1), with T3 also recording maximum 1000-grain weight (47.04 g). System performance metrics confirmed significant facilitation in T4 with maximum Land Equivalent Ratio (LER: 1.67), Area-Time Equivalent Ratio (ATER: 1.57) and Land Use Efficiency (LUE: 161.7%), which equates to a 67% increase in land utilization efficiency. Lupin was dominant in the wider arrangements (RCCba 4.67 in T4), while wheat dominated in the dense arrangements (Aggressivity A +0.49 and CR 2.19) in T7 [Wheat (15 cm spaced 10 crop rows: 1.5 m) + lupin (25 cm spaced 10 crop rows: 2.5 m)]. Spatial arrangement had a significant influence on biological weed control: the dense arrangement in T7 had the lowest weed biomass (1.61 g m-2) while the row gaps without shade in T4 resulted in higher weed biomass (3.45 g m-2). In general, T4 [Wheat (20 cm spaced 10 crop rows: 2 m) + lupin (40 cm spaced 5 crop rows: 2 m)] is suggested to be the best matrix to maximize the production of grain/feed, resource use efficiency, and profitability of the system.

Keywords: Crop Diversification; Land Equivalent Ratio; Resource Complementarity; Sustainable Agriculture; Weed Suppression; White lupine

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80. Assessment of Carbon, Energy and Water Footprints for Maize under Conventional and Regenerative Agriculture Systems

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Abstract: Global maize production is being affected by climate change, not only through direct effects like shifts in precipitation patterns and rising temperatures, but also indirectly through changes in the availability and effectiveness of agricultural inputs and a threat to ecological sustainability. In this context, evaluating the environmental footprint of maize cultivation has emerged as an essential approach for identifying climate-smart and sustainable farming practices. The carbon, energy, and water footprints of maize cultivation under two distinct systems Conventional Agriculture (CA) and Regenerative Agriculture (RA) were compared. The results demonstrated a clear distinction between the two systems: regenerative agriculture resulted in significantly lower carbon emissions of about 47% per hectare. Additionally, regenerative practices enhanced soil organic carbon sequestration through minimal disturbance, partially offsetting emissions from other sources. Energy analysis was also conducted using five core metrics: net energy (NE), energy use efficiency (EUE), energy productivity (EP), energy profitability (EPF), and human energy profitability (HEPF). These metrics enabled a detailed understanding of the energy dynamics of both systems. The findings revealed that regenerative agriculture outperformed conventional agriculture across all indicators. It required lower total energy inputs while maintaining comparable or higher yields, resulting in greater energy use efficiency 28%, higher values for energy profitability about 33% and human energy profitability further emphasized the reduced dependency on external energy sources and more efficient use of labor and machinery in regenerative systems. The water footprint analysis was divided into green water (rain-fed), blue water (irrigation), and grey water (the volume required to dilute pollutants). Agronomic estimations were used in addition to actual field measurements to generate the data. Results indicated that the total water footprint was significantly lower about 41% under regenerative agriculture. Reduced irrigation requirements were observed due to improved soil moisture retention, increased organic matter, and the use of mulching and cover crops. Grey water use was also reduced 55% because of minimal use of synthetic fertilizers and pesticides, leading to less chemical runoff and reduced water pollution. In regenerative plots, where improved soil structure and infiltration enabled crops to utilize rainfall more effectively, green water was utilized more effectively. The significant environmental benefits of regenerative farming over conventional farming were highlighted in this study. It also supported a shift toward farming practices that balance productivity with ecological integrity.

Keywords: Agroecology; Climate Change; Climate-resilient farming; Carbon footprint; Energy analysis; Regenerative Agriculture

81. Sustainable Potato Harvesting through an Indigenous Integrated Digger-Cum-Loader: Design Optimization and Field Performance

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Abstract: The traditional potato harvesting method in Pakistan is labour intensive, time-consuming, repeated handling of the crop and expensive due to higher operational costs, necessitating the need for sustainable mechanization solutions. The design, development and field evaluation of indigenous integrated potato digger cum loading mechanism to improve the harvesting efficiency, labour dependency and economic sustainability are presented in this study. A 3D computer-aided design (CAD) model was created and finite element analysis (FEA) was conducted on key parts such as the digging blade, main frame and mechanical assemblies. A digging blade angle of 24° was found to be the most appropriate structure through structural optimizing. A full scale prototype was made with local materials and components. This tractor mounted machine combines the advantages of cutting discs, digging blades, ridge compaction drums, three-stage conveyors, cleaning brushes, slip rollers, and elevator, allowing it to harvest two rows at once and load it directly into the trolley. Significant improvements over conventional harvesting practices were achieved in field testing. Labour requirements were reduced by about 78% and harvesting time reduced by 40-60%. Field efficiency went up from 65% to 82% and harvesting costs reduced by around 47%. These enhancements were achieved to a large degree by making the digging, the separation, the conveying and the loading of the soil into one continuous process - thus avoiding human collection and double handling of the crop. The results have shown the technical feasibility and economic benefits of indigenous potato harvesting machines. The integrated mechanization approach provides a practical, labour-saving and cost saving way to advance sustainable potato production, enhance potato farm productivity and engage in agricultural mechanization among potato farmers.

Keywords: Sustainable mechanization; Potato harvesting; Integrated digger-cum-loader; Structural optimization; Indigenous machinery.

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82. Simulating the Economic Impact of Nitrogen Application on Wheat Productivity under Arid Environment

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Abstract: Wheat (Triticum aestivum L.) is a major cereal crop essential for food security and agricultural sustainability, particularly in arid environments where efficient nitrogen (N) management is critical. This study evaluated the effects of different N rates on wheat growth, development, yield, and simulated productivity under arid conditions. The experiment was conducted at the Faculty of Agriculture and Environmental Sciences, MNS-University of Agriculture, Multan, Pakistan, using wheat cultivar Arooj-22 in a randomized complete block design with three replications. Four N treatments were evaluated: 0, 123.5, 185.25, and 247 kg N ha-1. Field observations included germination, emergence, leaf area index, phenological traits, yield components, and grain yield. The CERES-Wheat model within DSSAT was calibrated and evaluated using field data to simulate crop growth and yield responses to N management. Nitrogen application significantly improved most growth and yield-related traits compared with the control. The 185.25 kg N ha-1 treatment produced superior germination, emergence, leaf area index, grains spike-1, and 1000-grain weight, while 247 kg N ha-1 maximized plant height, tillers plant-1, grain yield, and harvest index. Overall, 185.25 kg N ha-1 was identified as an efficient N rate for optimizing wheat productivity under arid conditions.

Keywords: Nitrogen management; Wheat; Arid environment; Grain yield; Nitrogen use efficiency; CERES-Wheat; DSSAT

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83. Yield performance of maize hybrids under varying nitrogen levels in moderately saline-sodic soils

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Abstract: Soil salinity is a serious constraint limiting agricultural productivity worldwide. The higher concentrations of salts can disrupt the absorption and metabolism of essential nutrients and water in plants, thereby affecting physiological processes, and ultimately reducing the crop productivity. Maize, an economically important crop, possesses the ability to tolerate and adapt to varying levels of saline sodic soil conditions. However, it is imperative to comprehend the response of maize to moderate salinity and sodicity concentrations, and nitrogen rates on maize productivity. In this context, three years (2022, 2023 & 2024) field study was designed to evaluate the yield performance of spring-planted maize hybrids under different nitrogen levels in moderately salt-affected soil at Soil Salinity Research Institute, Pindi Bhattian. The experimental treatments consisted of four maize hybrids viz. FH-1036, YH-1898, YH-5427, and YH-5569; and four nitrogen levels viz. 75%, 100%, 125%, and 150% of the recommended dose of N fertilizer application. The experiments were conducted in RCBD under split-plot arrangement. The interactive effect of nitrogen and maize hybrids revealed that maximum chlorophyll contents (59.4), leaf photosynthetic rate (16.8 umol CO2 m-2 s-1), plant height (261.6 cm), number of leaves per plant (14.9), leaf length (79.6 cm), cob length (21.3 cm), number of grain rows per cob (18), number of grains per cob (526.1), thousand grain weight (347.7 g), grain yield (9.11 t ha-1), and biological yield (18.4 t ha-1) were recorded in maize hybrid YH-1898 with the application of nitrogen @ 125% of the recommended dose of N fertilizer application. The findings of the study revealed that saline sodic soils can inhibit crop growth, physiology and productivity through limiting the availability of nitrogen to plants, but higher rates of nitrogen application further support crop productivity. Thus, the study highlights that integrating an appropriate nitrogen level (125% RDF) with salt tolerant maize hybrid (YH-1898) is significant approach to enhance maize productivity in moderately saline sodic soil conditions.

Keywords: Climate change; Zea mays; nitrogen; soil salinity; sodicity; stress physiology; grain yield

84. Low-Cost Laser-Induced Graphene Sensors for On-Site Nitrate and Nitrite Monitoring: Enabling Precision Nutrient Management in Climate-Smart Agriculture

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Abstract: Inefficient nitrogen fertilizer use causes economic losses, nitrate leaching into groundwater, and nitrous oxide emissions that drive climate change. Farmers need affordable, rapid tools to monitor nitrate and nitrite in soil and water, but conventional laboratory methods are costly, slow, and inaccessible in the field. Laser-induced graphene (LIG) has gained considerable attention as an electrode material for electrochemical sensing because of its excellent electrical conductivity. In this research, LIG was directly synthesized on a polyimide substrate using a single-step laser irradiation technique, offering a simple, efficient, and rapid fabrication method. The effects of laser power on the electrical, morphological, and structural characteristics of the resulting LIG were systematically evaluated using Raman spectroscopy, X-ray diffraction (XRD), and scanning electron microscopy (SEM). Among the conditions examined, 57% laser power and 20% speed yielded the most favorable electrode characteristics, with low sheet resistance and a well-developed porous microstructure. The optimized electrodes were modified with cobalt oxide (Co_3O_4) and evaluated by cyclic voltammetry. In water samples, the sensors responded clearly across 1–100 ppm, with R^2 values of 0.95–0.98 for nitrate (logarithmic model) and 0.95–0.997 for nitrite (linear model). Validation on 25 real soil samples showed strong agreement with a commercial laboratory (Ward Laboratories), with $R^2 = 0.89$ and an average difference of only 2.2 ppm. These results show that Co_3O_4-modified LIG sensors offer a low-cost, portable alternative to laboratory testing. They can enable on-site nutrient monitoring, precise fertilizer application, and reduced nitrogen losses, supporting climate-smart agriculture and sustainable food security.

Keywords: Laser-induced graphene; cobalt oxide; electrochemical sensor; nitrate; nitrite; soil testing; climate-smart agriculture

85. Impact of Slow-Release Nitrogen Fertilizer on Hay Yield and Quality of Rhodes Grass

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Abstract: Rhodes grass (*Chloris gayana* Kunth) is a long-lived forage plant in Punjab, Pakistan. So, the amount of hay that Rhodes grass produces and the quality of that hay are often cut down by poor nitrogen management. When farmers use urea, a large portion of the nitrogen that is added is lost. The nitrogen leaves the soil as ammonia gas runs off as nitrate or is turned into gas during denitrification. These losses happen especially when the weather is hot and humid. The result is costs for farmers and pollution of air and water which goes against the ideas of climate-smart farming. A slow-release product like neem-coated urea can match the supply of nitrogen with the need of Rhodes grass. Thus, lower these losses. We do not know much about how Rhodes grass reacts to neem-coated urea when it is applied at different times. To learn more a field study will be carried out at Fongrow Private Limited in Khanewal, Punjab. The study will use a Complete Block Design with three repetitions. Factor A will test the timing of application - before the cut or after the first cut. Factor B will test four nitrogen treatments: 100 kg N ha^{-1} of urea split into one application (T1) and split into two applications (T2); and 100 kg N ha^{-1} of neem-coated urea split into one application (T3) and split into two applications (T4). For each treatment data will be taken for plant height, number of tillers, leaf-to-stem ratio, regrowth speed, green fodder yield, dry matter yield, crude protein, crude fiber and total ash. The data will be analysed by ANOVA. The mean differences will be compared with the LSD test at a 5 % significance level. We expect that neem-coated urea will keep nitrogen available for Rhodes grass during its growing period and during regrowth. This should improve how efficiently nitrogen is used, increase hay yield and improve forage quality while cutting nitrogen losses. The results of this work will help farmers use nitrogen in a way that's cheaper and better for the environment and will support sustainable fodder production and food security.

Keywords: Neem-coated urea; Slow-release nitrogen; Rhodes grass; Nitrogen use efficiency; Hay quality; Climate-smart agriculture

86. Integrating Remote Sensing and Crop Modeling for Climate-Smart Cereal Production in Northwest *China*

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Abstract: Climate variability and spatial differences in crop growth complicate efforts to sustain cereal production while using water and nutrients efficiently. This presentation synthesizes our progress in remote sensing, crop system modeling, and digital decision support, with a focus on wheat and maize production in the Guanzhong Plain and dryland systems in the Loess Plateau, China. Our research combines satellite time series, unmanned aerial vehicle observations, field measurements, the Agricultural Production Systems Simulator (APSIM), and machine learning to connect regional monitoring with field diagnosis and management assessment. Satellite applications include crop identification, growth monitoring, and a 2017-2024 irrigated cropland dataset for the Guanzhong region. Field-scale applications include mapping crop growth and predicting yield and quality from aerial observations. APSIM-based studies evaluate climate risks, sowing dates, and diversified cropping systems, while crop modeling combined with machine learning characterizes yield gaps in wheat-maize double cropping. Regional analyses indicate substantial spatial variation in crop conditions and a general north-to-south decrease in estimated yield gaps, supporting geographically differentiated management assessment. A digital platform provides crop information visualization, online crop simulation, and comparison of management options, supported by an experimental farm equipped for sensing and precision-management trials. Together, these developments provide a foundation for linking observed crop conditions with scenario-based agronomic decisions. We outline the next steps for evaluating effects on yield stability, water productivity, and nitrogen-use efficiency through coordinated field validation. Greenhouse gas mitigation remains an outcome to be quantified. The proposed integration pathway offers opportunities for collaboration with Pakistani researchers on locally calibrated models and farmer-oriented advisory services for climate-smart cereal production.

Keywords: climate-smart agriculture; remote sensing; APSIM; wheat-maize systems; yield gaps; decision support

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87. Bacteria-Assisted Rice Residue Management Through Fertigation: A Climate-Smart Practice for Wheat Production in the Rice-Wheat System

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Abstract: Rice residue burning, widely practiced clearing fields before wheat sowing in the rice–wheat belt of South Asia, releases greenhouse gases and smog, degrades soil health and compounds climate-related pressure on crop production. Climate-smart alternatives that retain residue without delaying sowing are therefore urgently needed. This study developed a non-burning, irrigation-integrated residue management practice using indigenous cellulolytic bacteria at MNS-University of Agriculture, Multan. Twelve isolates were evaluated in five sequential experiments: cellulolytic screening, a 28-day decomposition assay, a wheat-seedling growth-promotion bioassay, a pot trial testing accelerators and delivery methods (fertigation versus foliar spray), and a two-year field trial (2024–25 and 2025–26) in wheat. Isolate BS-4 ranked best, narrowing the residue C:N ratio by 72.80% and raising seedling vigor by 143.80% over controls. In the field, incubating bacteria-treated residue for 21 days before sowing, compared with no incubation, increased leaf-level water use efficiency by 166-182%, photosynthetic rate by 204-213% and stomatal conductance by 219-225%, and improved productive tillers (41-42%), biological yield (19.60%) and grain yield (41%). Adding BS-4 + compost applied through fertigation and BS-4 seed inoculation raised grain yield by about 60% over the combined control in both seasons. The practice also improved soil microbial biomass, cellulase activity and organic carbon. Delivering inoculants through irrigation water fits existing farm practice, offering a scalable climate-smart option that supports resilient wheat production.

Keywords: Rice residue management; Cellulolytic bacteria; Climate-smart agriculture; Fertigation; Water use efficiency; Wheat

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88. Simulating economic returns of fodder and grain maize production under varying nitrogen applications rate

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Abstract: Maize (*Zea mays* L.) is a significant cereal crop grown for grain, fodder, and silage. Its cultivation decreased during last year due to inflation; input prices hikes and low output rates. Its productivity is strongly influenced by nitrogen application. The purpose of this experiment was to evaluate the response of maize varieties to nitrogen application levels under arid conditions and to relate the agronomic response with economic return. The research has given the most optimum nitrogen level for good production of maize. The study considered two maize cultivars, P4040 (Grain maize) and H3131 (Fodder Maize), and nitrogen levels (i. N=0, ii. N=100, iii. N=175, iv. N=250, v. N=325) per hectare. The experiment was conducted at Agronomic research farm of Muhammad Nawaz Sharif University of Agriculture Multan under a randomized complete block design with split plot arrangement and three replications. CERES-Maize model embedded in DSSAT was used for simulation of maize crop. Important morphological, physiological, quality and yield-related traits were evaluated, including fodder yield, stem girth, leaves plant^{-1}, leaf area index, transpiration rate, cob length, grains cob^{-1}, cobs plant^{-1}, 1000 kernel weight and kernel rows cob^{-1}, stomatal conductance, grain yield, biological yield. Economic indicators were also included to identify the nitrogen rate that is agronomically productive and economically suitable. The results showed that nitrogen application improved growth, physiological, fodder, grain yield and quality traits. Plant height, fodder yield, biological yield, grain yield and grains cob^{-1}. P4040 performed better for grain yield while H3131 responded positively for vegetative traits and showed good performance in fodder yield and quality traits for the optimum nitrogen recommended level. The study further emphasized that the highest biological yield may not always represent the highest economic return because fertilizer cost increases with nitrogen rate. Simulation through CERES-Maize model was proposed as a decision-support approach to extend field results across weather and management scenarios. Overall, balanced nitrogen management is essential for improving maize productivity and profitability under arid conditions.

Keywords: Maize, Fodder, Grain, Yield, Nitrogen, Economic return, DSSAT, CERES-Maize, Benefit-cost ratio

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89. Valorization of orange peel powder in the development of a sustainable, nutrient-dense snack bar

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Abstract: Food insecurity, child undernutrition and underutilization of food processing by-products continue to be mutually linked issues in sustainable food systems. Integrated Food Security Phase Classification (IPC) analysis for 2025-26 indicated that over 2.71 million children aged 6-59 months were found to be acutely malnourished due to seasonality, the impact of floods and unavailability of nutrient dense foods in Balochistan, KPK and Sindh. Most of the current interventions such as fortified imports are expensive and a burden on the economy. Citrus peel, which accounts for 35-40% of fruit weight, is a significant by-product of citrus processing and is a source of vitamin C (45mg/100g), dietary fiber (40-49%), protein (4.5-6%), fat (1.5-4%) and phenolics for food products. Citrus peel powder was found to enhance the nutritional contents of bakery products, with dietary fibre content being increased from 2.73% to 13.60% in cookies and 2.70% to 13.33% in biscuits, besides improving polyphenols and antioxidant activity. Vitamin C increased from 0.79 to 1.01 mg/g in fortified wheat biscuits. These results indicate the possibility of citrus peel powder as a functional ingredient to enhance the nutritional value of food products. By using ingredients like orange peel, this study aims to produce a cost-effective, enriched snack bar. A plant-based snack like this can be formulated using dates as natural source of sweetness and energy, oats as a source of dietary fibre, peanuts as a source of protein and fats, and orange peel powder which could increase the fibre content and antioxidant activity. To make this study scientifically efficient the prepared bars will be subjected to nutritional composition, antioxidant activity, moisture, vitamin C, and sensory acceptability. This product represents potential for a circular food production system by utilizing citrus by-product into a food ingredient, with possible opportunities for small-scale food businesses. It will also benefit food-insecure communities by contributing to a reduction in the stress and costs associated with waste management.

Keywords: Orange peel, valorization, sustainable nutrition, food security, snack bars, enrichment, value addition.

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90. Agronomic Performance and Forage Quality of Five Napier grass varieties under Rainfed Conditions in the Pothwar Plateau, Pakistan

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Abstract: Seasonal fodder shortages, particularly in May–June and November–December, constrain livestock production in the rainfed Pothwar region of Pakistan. Napier grass (*Cenchrus purpureus*) is a promising perennial forage, but local evidence on how newer varieties perform without irrigation is scarce. We evaluated five varieties (Super Napier as check, Maize Napier, Sugarcane Napier, Sorghum Napier and Red Napier) in a randomized complete block design with three replications at the University Research Farm, Koont, Rawalpindi, in 2024. Growth, yield and quality traits were recorded at 120, 150, 180 and 365 days after planting. Varieties differed significantly for all traits ($p \leq 0.001$). Sorghum Napier was the tallest (285.2 cm) and produced the highest mean green fodder yield (120.1 t ha^{-1}), about five times that of Sugarcane Napier (23.3 t ha^{-1}), with a peak of 147.7 t ha^{-1} at the third cutting. Super Napier and Sorghum Napier led in dry matter yield (34.0 and 28.8 t ha^{-1}), while Red Napier produced the most tillers (20.8 per plant). Maize Napier had the highest crude protein (13.1%), whereas Sugarcane Napier recorded the highest crude fiber (35.5%), acid detergent fiber (41.7%) and neutral detergent fiber (61.4%), indicating lower digestibility. Delayed harvesting increased fiber and reduced protein; for instance, NDF in Sugarcane Napier rose from 56.4% to 66.3%, and crude protein in Maize Napier fell from 14.1% to 12.0%, revealing a clear trade-off between biomass and nutritive value. Sorghum Napier and Super Napier are therefore suited to maximizing biomass in rainfed systems, Maize Napier to dairy feeding where quality matters, while Sugarcane Napier showed limited adaptability. Harvest timing should be matched to the production goal.

Keywords: Napier grass; rainfed agriculture; forage yield; nutritive value; Pothwar; fodder scarcity

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91. Long-term organic and mineral fertilization effects on humic substance fractions and humification quality in contrasting Czech soils: implications for climate-smart soil carbon management

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Abstract: Soil organic matter (SOM) underpins nearly every dimension of soil health that climate‑smart agriculture (CSA) seeks to protect, from nutrient cycling and water retention to long‑term carbon storage. Yet the qualitative composition of SOM, particularly the balance between stable humic acids (HA) and more mobile fulvic acids (FA), remains poorly characterised across contrasting soil types and management histories. Long‑term fertilization experiments provide the only credible window into how organic and mineral amendments reshape humification over the timescales that matter for climate resilience. This study draws on 27 years of contrasting fertilization at four field sites in the Czech Republic, Haplic Luvisols at Hněvčeves and Červený Újezd, and Stagnic Cambisols at Humpolec and Lukavec, to quantify treatment effects on humic substances (HS), humic acid (HA), fulvic acid (FA), the HA/FA humification ratio, and the E_4/E_6 optical absorbance index. Seven treatments were maintained at all sites: unfertilized control (Cont), standard sewage sludge (SS1), triple‑dose sewage sludge (SS3), farmyard manure (FYM1), mineral N alone (N), balanced NPK, and mineral N with straw incorporation (N+St). Humic fractions were extracted following the IHSS protocol, carbon contents were determined by iodometric titration, and absorbance ratios were measured spectrophotometrically. Treatment effects were assessed by one‑way ANOVA with Fisher's LSD test, and Pearson correlation matrices were constructed for all five variables at each site. The results reveal a consistent and practically important divergence between amendment types. Triple‑dose sewage sludge (SS3) accumulated the greatest total HS across all four sites, but this gain was driven predominantly by FA enrichment rather than HA formation, yielding a qualitatively inferior, more labile organic matter pool. Farmyard manure (FYM1), by contrast, was the only treatment to maximise HA content, HA/FA ratio, and E_4/E_6 simultaneously at every site, with the HA/FA ratio exceeding 1.0 at Hněvčeves and Lukavec after 27 years a threshold indicative of well‑polymerised, stable SOM. Mineral nitrogen alone produced no measurable improvement in any humic fraction relative to the unfertilised control. A near‑perfect correlation between HA and E_4/E_6 ($r = 0.96–0.98$), reproduced consistently across all four sites, points to spectrophotometric E_4/E_6 measurement as a rapid, low‑cost proxy for HA accumulation in large‑scale soil carbon monitoring programmes. Site‑specific baseline differences were equally informative: the unfertilised control at Lukavec maintained an HA/FA ratio of 0.64, against only 0.39 at Humpolec, demonstrating that altitude, clay content, and soil mineralogy modulate baseline humification in ways that are entirely independent of management inputs. These findings carry clear practical relevance for CSA. Farmyard manure is the most effective long‑term strategy for building durable, HA‑dominated SOM in both Luvisols and Cambisols of Central Europe, whereas sewage sludge though valuable for raising total organic carbon predominantly enriches the labile FA pool and contributes less to long‑term carbon stability. The consistent HA–E_4/E_6 relationship offers a standardisable soil quality indicator, though the site‑specific baseline differences observed here reinforce the need for multi‑site validation before such indices are adopted as universal benchmarks. These results directly inform the design of fertilization strategies that advance the dual CSA objectives of sustained soil fertility and durable carbon sequestration.

Keywords: humic substances; HA/FA ratio; E_4/E_6 index; farmyard manure; sewage sludge; climate‑smart agriculture; soil carbon sequestration; long‑term fertilization.

92. IoT-Based Smart Irrigation Scheduling for Climate-Resilient Wheat Production in Water-Scarce Regions of Punjab, Pakistan

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Abstract: Climate change is intensifying water scarcity, erratic rainfall, and rising temperatures across the wheat-growing belts of Punjab, Pakistan, placing severe stress on crop productivity and threatening national food security. Conventional flood irrigation practices, still dominant among smallholder farmers, are highly inefficient and poorly suited to increasingly unpredictable climatic conditions. This study proposes and evaluates a low-cost, Internet of Things (IoT) based smart irrigation scheduling system designed to optimize water use efficiency in wheat production under climate-variable conditions. The system integrates soil moisture, temperature, and humidity sensors with a microcontroller-based data acquisition unit that transmits real-time field data to a cloud platform. A decision-support algorithm, calibrated using crop water requirement models and local agro-climatic data, generates automated irrigation schedules and delivers alerts to farmers via a mobile application. The system was piloted on wheat fields in a semi-arid district of Punjab over one complete cropping season, with performance compared against conventional farmer-managed irrigation practices on adjacent control plots. Preliminary field results indicate a reduction in total irrigation water application of approximately 25-30%, alongside improved consistency in soil moisture levels during critical crop growth stages such as tillering and grain filling. Wheat yield on IoT-managed plots showed a measurable improvement over control plots, attributed to more timely and precise irrigation aligned with actual crop water demand rather than fixed schedules. The findings demonstrate that affordable, locally adaptable smart irrigation technologies can significantly enhance water-use efficiency and climate resilience in smallholder wheat farming systems. The proposed system offers a scalable model for integrating digital agriculture and precision irrigation technologies into national Climate-Smart Agriculture strategies, supporting Pakistan's broader goals of sustainable food security, efficient natural resource management, and climate change adaptation in the agriculture sector.

Keywords: Climate-Smart Agriculture; IoT; Smart Irrigation; Water Use Efficiency; Wheat Production; Precision Agriculture; Climate Resilience

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93. Carbon Leakage Relocated, Not Reduced: Structural-Break Evidence on Embodied-Carbon Trade Diversion after the 2018 US–China Tariff War

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Abstract: Whether unilateral tariffs and "reshoring" policies genuinely reduce the carbon footprint of national consumption, or merely displace it to third countries, is a live and empirically unsettled question in climate and trade policy. We test this using the newest (2024) vintage of the Global Carbon Project's national territorial and consumption-based CO_2 emissions accounts (1990–2022) for ten major economies. Applying Mann-Kendall trend tests, Sen's slope estimators, and Chow structural-break tests centred on 2018 — the year the United States imposed the first major tariff tranche on Chinese goods - we find that the aggregate net imported-carbon balance of the United States shows a statistically significant long-run upward trend (Sen's slope = 0.020 $GtCO_2\ yr^{-1}$, $p < 0.0001$) but no detectable structural break at 2018 (Chow $F = 0.54$, $p = 0.59$): the trade war did not measurably alter the trajectory of the carbon embodied in US consumption. In contrast, several prospective "China-plus-one" trade-diversion destinations show sharp, statistically significant post-2018 accelerations in their role as net exporters of embodied carbon — most strikingly Vietnam (Chow $F = 42.2$, $p < 0.0001$) and India ($F = 5.50$, $p = 0.0095$) - while China's own net embodied carbon exports resumed accelerated growth after 2018 ($F = 8.14$, $p = 0.0016$) following a 2008–2015 slowdown consistent with the literature. These results indicate that the 2018 tariff escalation reorganised the geography of embodied-carbon trade without reducing its aggregate magnitude for the importing country — a finding with direct relevance to the design of carbon border adjustment mechanisms, which typically target country of final assembly rather than the full upstream carbon content of traded goods. We discuss implications for US trade and climate policy and for the evaluation of reshoring and "friendshoring" strategies as climate tools.

Keywords: carbon leakage; consumption-based emissions; trade diversion; structural break analysis; Global Carbon Budget; US–China trade war; carbon border adjustment

94. Physiological Enhancements Improve Wheat Productivity under Late Sowing Conditions

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Abstract: Wheat sowing is delayed in Rice-Wheat and Cotton-Wheat rotations. It exposes late-sown wheat to low and high temperature stresses at germination and grain development stages, respectively, affecting the growth and productivity of wheat. Therefore, this study evaluated the effect of late-sowing on wheat performance and the potential of seed treatments to alleviate yield losses in late-sown wheat. Field experiments were conducted during 2021–2022 at Bahawalpur (EL1) and Multan (EL2), Pakistan. A split-plot randomized complete block design with three replications was used at both locations, with sowing date as the main-plot factor and seed treatment as the subplot factor. Sowing was performed on 15 November 2021 for recommended sowing, and 15 December 2021 for delayed sowing at both experimental locations. Seeds were subjected to five treatments: heat treatment, cold treatment, zinc priming, proline priming, and untreated control. Late sowing reduced grain yield of untreated plants by 38.6% at Bahawalpur and 67.5% at Multan and decreased their germination index by 21.4% and 25.8%, respectively. It also reduced plant growth, spike development, and yield-related traits, although the magnitude of these effects differed between locations. Heat treatment improved germination under late-sown conditions and produced the highest late-sown grain yield at Bahawalpur (5.11 t ha^{-1}). Zinc priming produced the highest late-sown grain yield at Multan (2.48 t ha^{-1}), while zinc and proline priming generally improved growth, spike traits, physiological performance, and grain yield. Zinc and proline priming also enhanced antioxidant responses, although treatment effects were location dependent. Cold treatment provided no consistent benefit and resulted in poor crop establishment under delayed sowing at Multan. Based on this one season and two locations study, heat treatment, zinc priming and proline priming showed potential for improving late-sown wheat performance, whereas cold treatment was unreliable under the tested conditions. However, broader multi-season and multi-location validation is required before general recommendations are made.

Keywords: Delayed sowing; Heat stress; Thermal seed treatment; Zinc seed priming; Proline seed priming; Antioxidant activity; Triticum *aestivum*

95. Environmental Laws in Pakistan and the International Legal Framework

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Abstract: Environmental protection has become a global priority as climate change, biodiversity loss, pollution, and resource depletion continue to threaten sustainable development. International environmental law, through instruments such as the United Nations Framework Convention on Climate Change (UNFCCC), the Paris Agreement, and the Convention on Biological Diversity (CBD), provides a legal framework for countries to reduce emissions, conserve ecosystems, and promote climate resilience. These agreements encourage states to adopt effective environmental policies while balancing economic growth and social welfare. Pakistan, although contributing less than one percent of global greenhouse gas emissions, is among the countries most vulnerable to climate change. In response, Pakistan has strengthened its legal framework through the Pakistan Environmental Protection Act 1997, the National Climate Change Policy, the Climate Change Act 2017, and provincial environmental protection laws following the 18th Constitutional Amendment. The country has also introduced initiatives such as large-scale afforestation, renewable energy projects, and the National Adaptation Plan to enhance climate resilience. Furthermore, the judiciary has played a significant role in enforcing environmental rights by recognising the constitutional right to a clean and healthy environment. Continued implementation of these laws, stronger institutional capacity, and international cooperation remain essential for Pakistan to effectively address environmental challenges and fulfil its international legal obligations.

Keywords: Environmental Law and Climate Governance: A Comparative Analysis of International Legal Frameworks and Pakistan's Environmental Regime

96. Precision Genome Editing of Sugarcane for Enhanced Sucrose Accumulation and Abiotic Stress Tolerance

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Abstract: Sugarcane (Saccharum spp.) is a cornerstone crop for global sugar production and renewable bioenergy, yet its future productivity is increasingly threatened by climate instability and the intensification of abiotic stresses. The intrinsic complexity of the sugarcane genome, characterized by extensive polyploidy, aneuploidy, and high heterozygosity, has historically constrained efforts to dissect gene function and accelerate trait improvement. Emerging precision genome-editing technologies are now reshaping the landscape of sugarcane biotechnology by enabling targeted manipulation of regulatory networks underlying carbon partitioning, sucrose accumulation, and stress adaptation. Beyond conventional trait engineering, CRISPR/Cas-based approaches provide unprecedented opportunities to interrogate and reprogram the molecular architecture of sucrose metabolism and environmental resilience. Strategic editing of key metabolic regulators, transcriptional networks, and stress-responsive pathways can optimize source–sink dynamics, enhance carbon allocation toward sucrose storage, and reinforce cellular mechanisms governing drought, salinity, and thermal stress tolerance. The convergence of genome editing with pan-genomics, single-cell approaches, multi-omics integration, and predictive breeding frameworks is opening new avenues for designing next-generation sugarcane ideotypes tailored to future climatic scenarios. This perspective highlights the emerging paradigm of precision genome engineering as a catalyst for transforming sugarcane improvement from phenotype-driven selection toward knowledge-guided crop design. Harnessing these technologies will be critical for developing high-sucrose, climate-resilient sugarcane varieties capable of sustaining productivity, supporting bioenergy transitions, and strengthening global agricultural resilience under a changing climate.

Keywords: Saccharum spp.; precision genome engineering; CRISPR/Cas; sucrose metabolism; climate resilience; abiotic stress adaptation; crop design

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97. Long-Term Alpine Grassland Restoration through Furrow Sowing and Integrated Microbial–Nitrogen Fertilization

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Abstract: Grasslands sustain biodiversity, sequester carbon, maintain productivity, and support pastoral livelihoods, yet these ecosystems are increasingly degraded by climatic variability and human disturbance. Such pressures threaten biodiversity, climate regulation, and local livelihoods, highlighting the need for long-term active restoration. We conducted a six-year (2020-2025) factorial field experiment in a severely degraded alpine grassland in the Gannan Tibetan Autonomous Prefecture. Treatments comprised two sowing methods (flat and furrow), two native seed mixtures (Elymus nutans + Avena sativa and E. nutans + Lolium multiflorum), and four fertilization regimes (control, nitrogen [N], microbial [M], and combined N+M) across 48 experimental plots. Data were evaluated using split-plot-in-time analysis of variance, with year treated as the repeated factor. Plant diversity, soil nutrient pools, soil enzyme activities, and an integrated ecosystem multifunctionality (EMF) index were assessed annually. Furrow sowing increased species richness by 8.3% relative to flat sowing and resulted in significantly higher Shannon and Simpson diversity. Sowing method and restoration year were the principal drivers of plant diversity, which showed a non-monotonic pattern: diversity declined until 2022-2023 and subsequently recovered by 2025. Seed mixture and fertilization exerted only minor, index-specific effects on diversity. By contrast, soil nutrients, enzyme activities, and organic carbon responded strongly and consistently to fertilization. Combined N+M increased total N by 25.0%, available P by 26.9%, soil organic carbon by 11.6%, and urease activity by 33.7%. Ecosystem multifunctionality rose from -0.337 in 2020 to 0.422 in 2025 ($F = 122.57$, $p < 0.001$). Mean multifunctionality was highest under combined fertilization (0.427) and lowest in control (-0.523; $F = 85.20$, $p < 0.001$). These results indicate that furrow sowing and fertilization promote recovery through largely independent pathways and that their combined application offers the most effective long-term strategy for restoring degraded alpine grasslands.

Keywords: Alpine grassland; ecosystem multifunctionality; microbial fertilizer; soil-vegetation coupling; plant diversity; restoration ecology; soil enzyme activity; Tibetan Plateau

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98. Model-Based Water Accounting for Climate-Resilient Agriculture in Pakistan's Indus Basin, Punjab and Sindh

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Abstract: Water accounting quantifies how much water is available, how much is needed and by whom, and where and when demand goes unmet. In Pakistan's Indus Basin, irrigated agriculture accounts for over 90% of withdrawals, abstractions are largely unmetered, and canal water and groundwater are used conjunctively. Statistical frameworks that rely on metered use cannot capture this, and existing Indus models were built for economic optimisation or operational allocation, not for mapping the water balance of each canal command area. A model-based water accounting (WA) system was therefore designed for the Indus Basin within Pakistan covering Punjab and Sindh provinces specifically. It improves on conventional water accounting in three ways: it distinguishes demand from actual use, so supply–demand gaps become visible; it models terms that cannot be observed directly, such as return flows; and it extends the accounts from the historical period to future scenarios. It is built on the Water Evaluation and Planning (WEAP) model, which is freely available to and already used by Pakistani institutions. The system is flexible in space and time. The 45 canal command areas (31 in Punjab, 14 in Sindh) are the basic accounting units, and separate nodes cover the areas outside them, including the major cities of Lahore, Karachi and Islamabad, so results aggregate from command area to province and basin. The model runs monthly, and accounts can be compiled per kharif or rabi season, per year or over several years. A dashboard lets stakeholders who do not operate WEAP view the results at basin, provincial and canal command scale. Inputs draw largely on remote sensing products, checked against in-situ records, so datasets can be updated as new observations become available. The WA system is calibrated against observed river discharges. Data gathering and model development are carried out with support from local institutes in Punjab and Sindh. The accounts separate green from blue water and are summarised in indicators such as blue water stress, unmet demand and SDG indicator 6.4.2. The system also assesses two kinds of scenario: projections, such as climate change and demand growth, and interventions, such as infrastructure development and management measures. Comparing each scenario with the historical baseline shows where and when supply–demand gaps widen and how far interventions could narrow them, informing water allocation planning and climate-smart agriculture.

Keywords: water accounting; Indus Basin; canal command areas; WEAP; remote sensing; scenarios; climate-smart agriculture

99. Climate Change Impacts on Water Consumption, Yield, and Water Productivity of Major Crops in Punjab, Pakistan

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Abstract: Punjab province faces increasing challenges from climate change, including rising temperatures and changing rainfall patterns that are expected to affect crop water requirements and productivity. To support climate-resilient agricultural planning, a decision-support tool is being developed under the FAO Green Climate Fund (GCF) project to assess future impacts on evapotranspiration (ET), crop yield, and water productivity (WP). The tool integrates climate projections with crop water requirement and productivity models to evaluate the long-term performance of key crops, including wheat, rice, and cotton, across Punjab. Future ET, yield, and WP are assessed under alternative climate scenarios over the next five decades, enabling comparison of anticipated changes in agricultural water demand and productivity. The study will present projected trends in ET, yield, and WP under selected climate scenarios and identify potential implications for irrigation management, water allocation, and agricultural adaptation. Future enhancements of the tool will include additional crops, adaptation measures, and expanded decision-support functions to strengthen climate-resilient water and agricultural management in Punjab.

Keywords: Climate change; Water productivity, Actual evapotranspiration, Aquacrop, Agroecological zone, Wheat, Maize, Sugarcane, Cotton, Rice

100. F1 hybrid gave Improvement in Relation to Heat Response in SlHSFA3 gene in Tomato (*Solanum Lycopersicum*)

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Abstract: Heat shock factors (HSFs) are transcription activators of heat shock proteins under cellular stress condition specifically under heat stress. There are three main classes of HSFs, i.e., HSFA, HSFB, and HSFC. HSFA3 is member of HSFA1 clade (i.e., a/b/d/e) contributing significantly to basal and acquired thermotolerance. In present research SlHSFA3 gene was assessed for the expression variation in tomato hybrids and change in variation in response after hybridization. Contrasting genotypes for heat tolerance were crossed and F1 combinations with their parents were analyzed for gene expression. Reverse transcriptase polymerase chain reaction was used to analyze gene expression in leaves of five- week - old tomato seedlings following heat stress treatment (45°C) and control condition(25°C). Strong upregulation of the desired gene SlHSFA3 was observed in cross 10145×17903 under heat treatment as compared to control condition. In parent genotypes of this cross i.e., 10145 and 17903, a little upregulation was observed after heat treatment when compared to control. In general, the upregulation of gene suggested improvement in heat response of tomato F1 hybrid in cross 10145×17903 after heat treatment. Same pattern of expression was observed for the cross. i.e., SAMRUDHI × 17903. These expression trends of SlHSFA3 gene upon heat treatment revealed that the F1 hybrid gave improvement in relation to heat response.

Keywords: Tomato, heat stress, heat shock factors, F1 hybrids

101. Phylogenetic and Expression Dynamics of SlHSP 70.1 gene in F1 Tomato Hybrids under Heat stress

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Abstract: Heat shock proteins (HSPs) are stress-responsive molecular chaperones uphold proper protein folding in response to external and internal stresses. HSP 70 molecular chaperones playing substantial role in plant thermotolerance. Present study was conducted to investigate the expression dynamics of SlHSP 70 genes in tomato in response to heat stress and to explore evolutionary relationship. Using bioinformatic tools, 21 members of HSP 70 family were identified. Insilico sub cellular localization indicated that most of the members of HSP70 gene family localized in cytoplasm. For evolutionary relationship study, a total of 43 of SlHSP70 genes were included in the phylogenetic tree showing a hierarchical ancestral relationship of the HSP 70 genes shared by the members of the kingdom plantae, archea, chromista, Fungai and bacteria. Reverse transcriptase polymerase chain reaction was used to analyze gene expression in leaves of five- week - old tomato seedlings following heat stress treatment (45°C) and control condition(25°C). In F1 hybrid of cross SAMRUDHI ×17903 no expression of SlHSP70.1 gene was observed under control condition but enhanced after heat shock treatment. Desired gene was not expressed among the parents under control and treated condition except for 17903, where upregulation in expression was observed after heat treatment. These expression results, depicting SlHSP70.1 gene was differentially expressed in parents and hybrids and intensify in F1 hybrid after treatment at 45°C. So, the merging of two genomes by hybridization lead to the remodeling of parental gene expression in hybrids of this cross.

Keywords: Tomato, heat stress, heat shock factors, F1 hybrids

102. Identification and Characterization of Plant Growth-promoting Rhizobacteria (PGPR) from Grasses of Cholistan Desert and their Effect on the Development of Maize (*Zea mays* L.)

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Abstract: Maize (*Zea mays* L.) is an important cereal and multipurpose crop belonging to family *Poaceae*, providing a lot of benefits such as food for humans, feed for animals and poultry, and is used as a fodder for livestock, as well. The rhizosphere is the narrow zone of soil in close contact with plant roots. Along with the root exudates, rhizosphere is important for variety of useful microbes, particularly bacteria. The rhizospheric bacteria may directly or indirectly help the plants in growth improvement as well as immunity strengthening. Cholistan desert is spread along the Eastern border of Pakistan in Bahawalpur division. There are some wild grasses growing in Cholistan deserts which are drought tolerant and open horizons to investigate drought tolerance mechanism. Considering previous reports of the role of PGPR in inducing and/ or strengthening drought tolerance, current study was designed to identify and characterize PGPR in rhizosphere of some wild grasses of Cholistan deserts. This work carried out a morphological, metabolic, and molecular characterization of rhizobacteria associated with grasses rhizosphere, evaluating the positive effects of bacterial inoculation on plants under drought conditions. The evaluated strains were taxonomically affiliated -based on the 16S rRNA gene- as *Bacillus subtillis* (C-3), *Enterobacter cloacae* (C-4) and *Exigoubacterium* Sp. (C-20). All these strains were able to synthesize indoles, produce siderophores, and solubilize phosphates. The individual inoculation of these strains to maize plants showed a significant increment (compared to un-inoculated plants) in height (40-60 %), shoot dry weight (210-360 %), root dry weight (103-304 %), and SPAD values (20- 47 %). The native bacteria associated with maize in the rhizosphere of some grasses in Cholistan desert are a promising alternative to promote the growth of their host plant and contribute to sustainable maize production.

Keywords: Microbial inoculants; Plant growth promotion; Soil; Maize; Cholistan

103. Review on Regenerative Agriculture: A Pathway Toward Climate-Resilient and Sustainable Food Systems

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Abstract: As the planet faces unprecedented environmental and climatic pressures, regenerative agriculture offers a framework for radically rethinking how food is produced. In contrast to most industrial forms of farming that damage soils and increase greenhouse gas emissions, regenerative practices harness nature's processes to enhance soil health, promote biodiversity, and strengthen ecosystem functions that support resilient food systems. Building on practices such as cover cropping, diverse crop rotations, minimal tillage, and agroforestry, regenerative agriculture increases the capacity to sequester carbon in soils and resources. Not only does it improve water retention, but it also buffers agricultural landscapes against extreme weather events, which are essential pillars of climate resilience and sustainability. However, barriers to adoption, such as economic considerations, knowledge gaps between scientists and farmers on regenerative practices, and disconnected governance policies, need to be addressed via an integrated framework that reinforces linkages among science, efficiency, and evidence-based framing of incentives provided to growers (e.g., Marketplace providers), whilst ensuring informed policy support by decision makers towards scaling aligned, transformative outcomes across agrifood systems. This review synthesizes the latest available research on regenerative principles and on the effectiveness of climate mitigation and adaptation, alongside sustainable pathways for scaling up domestic to global uptake of regenerative agriculture. It connects ecological science with socio-economic factors to present regenerative agriculture not as a niche practice, but as a fit-for-purpose option toward climate-resilient and sustainable food systems.

Keywords: regenerative agriculture, climate resilience, soil health, sustainable food systems, carbon sequestration, biodiversity conservation, agroecology

104. Roots-Based Breeding for Developing Drought Resilient Wheat Varieties

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Abstract: Climate change threatens cereal-based food security: 673 million people faced hunger in 2024, and without adaptation, CO_2 fertilization or genetic improvement, every 1 °C rise in global temperature would reduce wheat yield by about 6%. In Pakistan, drought and terminal heat can strike together, as in 2022. Record-breaking heat in March-April, with March rainfall 62% below normal, cut national wheat production by 3.9% to 26.39 million tonnes and CIMMYT trials recorded yield losses of 15-20% in the Punjab. Roots determine access to stored soil water, yet they remain under-used in breeding because they are difficult to phenotype in the field. In a Seri/Babax wheat population, five of six sister lines with deeper root mass, cooler canopies and longer grain filling outyielded the best parent by up to 35% under drought. Cooler-canopy genotypes extracted 35% more water from the 30-90 cm soil layer under drought, but under hot, irrigated conditions their roots concentrated in the upper 60 cm, a clear genotype-by-environment interaction. Root architecture is also genetically tractable: a major QTL on chromosome 6A shifted seminal root angle by 7.7° in durum wheat without changing root biomass, and in rice, DRO1 introgression produced deeper roots and higher yield under drought. We propose a root-based breeding pipeline built on (i) the steep, cheap and deep root ideotype ; (ii) high-throughput root and canopy-temperature phenotyping combined with genomic selection and marker-assisted introgression of root-angle QTL; (iii) speed breeding, allowing up to six generations per year; (iv) multi-environment testing under drought, heat and irrigated conditions; and (v) selection for beneficial root–microbe interactions, since a synthetic community of four drought-tolerant bacterial taxa improved wheat growth under drought. The potential is substantial but context dependent. Simulations in southern New South Wales, Australia, showed that access to subsoil water at 1.2-1.8 m can raise wheat yield by 0.1-0.6 t/ha, with the largest gains in wetter seasons and environments. Root-based breeding therefore offers the greatest returns where water exists in depth, and it must be paired with multi-environment testing. Integrated with heat tolerance and agronomic management, it can deliver drought and heat smart varieties that stabilize yields, reduce risk for smallholders and support sustainable wheat production in Pakistan.

Keywords: Root system architecture; Drought and heat tolerance; Genotype-by-environment interaction; Root-microbe interactions; Speed breeding

105. Assessing Herbicide Carryover in Winter Crops and Implication for Sustainable Crop Production

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Abstract: Herbicide carryover is major challenge to sustainable agriculture because herbicide residue can adversely affect germination and growth of succeeding crops. This study evaluated the carryover effects of pendimethalin and S-metolachlor on seven winter crops under a glasshouse bioassay. The experimental soils included control (no herbicide application), one month-aged pendimethalin residue (MAPR), one month-aged S-metolachlor residue (MASR), season-aged pendimethalin residue (SAPR), and season-aged S-metolachlor residue (SASR). Seven winter crops including wheat, oat, barley, chickpea, lentil, berseem and raya were grown in aforementioned soils. Results showed that emergence of wheat reduced from 93.33 % (control) to 58.33% in SAPR, while root and shoot length reduced by 43 and 29%, respectively. Photosynthetic rate dropped from 17.92 to 3.91 µmol CO2 m-2 s-1 and water use efficiency declined from 5.36 to 3.29 kg ha-1 mm-1. Oats root length decreased by 44%, while sub-stomatal conductance in barley decreased from 248.25 to 67.25 µmol H2O m-2 s-1. Chickpea emergence declined from 90 to 47.50%, and lentil seedling biomass decreased by 17%. Overall, seedling dry biomass reduction followed the order: raya (72%) > barley (44%) > chickpea (41.4%) > berseem (41.3%) > wheat (26%) > oat (23.5%) > lentil (11.5%). The conducted study confirms significant residual toxicity of pendimethalin and S-metolachlor to subsequent crops.

Keywords: Herbicide residue; soil applied herbicides; pre-emergence; pendimethalin; residual toxicity; S-metolachlor

106. Modulating Cotton Growth, Physiological Performance and Yield through Moringa Leaf Extract and Gibberellic Acid Application

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Abstract: Cotton (Gossypium hirsutum L.) is an essential fibre crop which has a significant contribution in textile industry and agriculture economy of Pakistan. But environmental stress (heat, drought, and insufficient nutrient management) has a significant impact on cotton productivity. In this context, use of plant biostimulants and growth regulators are regarded as effective strategies to enhance the growth and yield of crops. Thus, the present study was designed to investigate the combined effect of moringa oleifera dry leaf extract (MDLE) and gibberellic acid (GA_3) on growth, physiology and yield of cotton.The experiment was conducted at MNS University of Agriculture, Multan in a randomized complete block design (RCBD) with three replications. Ten treatments were carried out comprising various rates of MDLE alone and at 2% MDLE + 100PPM GA3. The data obtained for phenological, physiological and yield characteristics were analysed statistically using ANOVA and Tukey's HSD test at 5% probability level. The outcomes revealed that there was significant enhancement in the crop performance in the combined application of MDLE and GA_3. Treatment T10 (2% MDLE + 100 ppm GA_3) had earlier initiation of square, flowering, boll formation, and boll opening than the control. Improvements in physiological traits like stomatal conductance, chlorophyll content and water use efficiency were also observed. Furthermore, it was noted that combined treatments resulted in higher boll number, boll weight, plant height and seed cotton yield. Overall, the application of MDLE in combination with GA_3 proved to be a beneficial and environmentally friendly method to improve cotton growth, physiology and yield. Such method could be useful for enhancing sustainable cotton cultivation in the future under the changing climate.

Keywords: Moringa Oleifera, Gibberellic acid, Bio Stimulants, Cotton

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107. Influence of Spatial Arrangement on Crop Performance and Productivity in Maize-Soybean Intercropping

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Abstract: Cereal-legume intercropping is a practical pathway for improving biological efficiency, weed suppression and land productivity in resource-limited environments. A field experiment was conducted during spring 2025 at the Research Farm of MNS University of Agriculture, Multan, Pakistan, to evaluate the agronomic performance of maize (*Zea mays* L.)-soybean (*Glycine max* L. Merr.) intercropping under different planting configurations. The experiment was arranged in a randomized complete block design with three replications and five treatments: sole maize, sole soybean, 2:2 maize:soybean, 2:4 maize:soybean and 4:2 maize:soybean. Weed pressure, emergence, growth, physiological traits, yield components, component-crop yields and land equivalent ratio (LER) were measured. The 2:2 configuration was the most suppressive against weeds and reduced weed density, weed frequency and weed dry weight to 22.33 plants m^{-2}, 30.37% and 95.09 g m^{-2}, respectively. Sole maize produced the highest maize grain yield (8778.67 kg ha^{-1}), but the 4:2 system was statistically comparable (8278.33 kg ha^{-1}) and had the highest maize LAI, stem diameter, chlorophyll content, photosynthetic rate and biological yield among intercropped treatments. Sole soybean produced the highest seed yield (1068.00 kg ha^{-1}), whereas the 2:4 configuration preserved soybean growth and seed yield better than the more maize-dominant system. All intercrops produced LER values greater than 1.0, with maximum values in 4:2 (1.75) and 2:4 (1.73). The results indicate that planting geometry strongly regulates competition and complementarity in maize-soybean intercropping, with 4:2 best for maize yield and land-use efficiency, 2:2 best for weed suppression and 2:4 better where soybean contribution is prioritized.

Keywords: Cereal-legume Intercropping; Land equivalent ratio; Maize; Planting geometry; Soybean; Sustainable intensification; Weed suppression

108. Optimizing Spatial Arrangement and Nitrogen Supply for Enhanced Land-Use Efficiency in Wheat-Canola-Chickpea Intercropping

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Abstract: Cereal-legume intercropping is a practical pathway for improving biological efficiency, weed suppression and land productivity in resource-limited environments. A field experiment was conducted during spring 2025 at the Research Farm of MNS University of Agriculture, Multan, Pakistan, to evaluate the agronomic performance of maize (*Zea mays* L.)-soybean (*Glycine max* (L.) Merr.) intercropping under different planting configurations. The experiment was arranged in a randomized complete block design with three replications and five treatments: sole maize, sole soybean, 2:2 maize:soybean, 2:4 maize:soybean and 4:2 maize:soybean. Weed pressure, emergence, growth, physiological traits, yield components, component-crop yields and land equivalent ratio (LER) were measured. The 2:2 configuration was the most suppressive against weeds and reduced weed density, weed frequency and weed dry weight to 22.33 plants m^{-2}, 30.37% and 95.09 g m^{-2}, respectively. Sole maize produced the highest maize grain yield (8778.67 kg ha^{-1}), but the 4:2 system was statistically comparable (8278.33 kg ha^{-1}) and had the highest maize LAI, stem diameter, chlorophyll content, photosynthetic rate and biological yield among intercropped treatments. Sole soybean produced the highest seed yield (1068.00 kg ha^{-1}), whereas the 2:4 configuration preserved soybean growth and seed yield better than the more maize-dominant system. All intercrops produced LER values greater than 1.0, with maximum values in 4:2 (1.75) and 2:4 (1.73). The results indicate that planting geometry strongly regulates competition and complementarity in maize-soybean intercropping, with 4:2 best for maize yield and land-use efficiency, 2:2 best for weed suppression and 2:4 better where soybean contribution is prioritized.

Keywords: cereal-legume intercropping; land equivalent ratio; maize; planting geometry; soybean; sustainable intensification; weed suppression

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109. Climate-Smart Agronomic Practices and Adaptive Farm Management Strategies for Resilient and Sustainable Agriculture under Climate Change

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Abstract: Because of rising temperatures, changing precipitation patterns, frequent droughts and floods, extreme heat events, degraded soil, and increased pressures from pests and diseases, climate change presents a serious and growing threat to agricultural systems. Crop productivity, soil health, water use efficiency, farm profitability, and ultimately the security of food and livelihoods worldwide can all be significantly hampered by these climate stresses. Climate-smart agronomic practices and adaptive farm management techniques must thus be combined to increase agricultural resilience. Production risks under climate uncertainty can be reduced by using early-maturing and climate-resilient cultivars, optimizing when to plant and harvest, and diversifying cropping systems. Improved soil-moisture management, mulching, conservation tillage, rainwater collection, farm-pond construction, and efficient irrigation can all increase drought resilience and water-use efficiency. Additionally, site-specific nutrient management, organic amendments, cover crops, crop rotation, and intercropping can enhance soil quality and long-term productivity. Integrated pest management can lessen reliance on synthetic pesticides and reduce pest outbreaks brought on by climate change. Agroforestry can further enhance ecosystem resilience by moderating microclimatic conditions, reducing erosion, conserving biodiversity, and providing supplementary farm income. In addition, timely access to climate information, agricultural extension services, crop insurance, improved post-harvest infrastructure, and precision farming technologies can strengthen farmers' adaptive capacity. Collectively, these integrated approaches offer a pathway toward resilient, resource-efficient, and environmentally sustainable agricultural production under a changing climate.

Keywords: Climate-Smart Agronomic Practices and Adaptive Farm Management Strategies for Resilient and Sustainable Agriculture under Climate Change

110. Foliar Application of Boron Combined with Seed Inoculation with Boron Tolerant Bacteria (*Bacillus* sp. MN-54) and Biochar Improved Growth and Productivity of Maize

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Abstract: Boron (B) deficiency affects the growth and productivity of crop plants and numerous management practices are used to improve crop performance. Large-scale maize production in Pakistan's arid and semi-arid regions has low soil fertility. B deficiency restricts maize production in such soils and yields. Several organic and inorganic (foliar application) adaptations are employed to recover soil fertility. The pot experiment on maize was designed as a complete randomized design (CRD) under a factorial arrangement with three replications. B foliar application (0.0, 0.01, 0.05, 0.10 %) and biochar were used in the treatment of 5% (w/w). Boron Tolerant Bacteria (BTB) (*bacillus sp.* MN-54) is used for the inoculation of seeds. The grain yield (30%) and B-grain concentration (13%) were enhanced with 0.05% B foliar application followed by 0.01%. Stomatal conductance (21%), photosynthetic rate (10%), transpiration ratio (35%) and chlorophyll content (23%) were increased with the application of *bacillus sp*. MN-54 and biochar. Plant height, the number of grains per cob, grain yield, biological yield, and harvest index were increased with a foliar application at 0.05% B and BTB inoculation. Biological yield can be enhanced by using a foliar spray at 0.05% with biochar and inoculation of bacteria (BTB).

Keywords: Foliar Spray, Boron, Boron Tolerant Bacteria, Biochar

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111. Climate-Smart Agronomic Strategies for Enhancing Agricultural Resilience and Sustainable Food Security

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Abstract: Climate change is increasingly impacting agriculture through higher temperatures, unpredictable rainfall, droughts, floods, heat waves, soil degradation, and greater pest and disease pressure. These factors can lower crop yields, reduce water-use efficiency, raise production costs, and threaten farmers' livelihoods and food security. To address these challenges, practical climate-smart agronomic solutions are needed to build resilience and maintain productivity. Farmers can adopt climate-resilient and early maturing crop varieties, adjust sowing and harvest dates based on weather patterns, and diversify crops to manage risk. Water conservation can be achieved through efficient irrigation, rainwater harvesting, farm ponds, mulching, conservation tillage, and effective soil moisture management. Soil fertility and health can be improved with crop rotation, intercropping, cover crops, compost, farmyard manure, and balanced fertilizer use. Integrated pest management helps reduce pest losses and pesticide reliance, while agroforestry can lower heat stress, prevent erosion, enhance biodiversity, and provide additional income. Access to weather forecasts, extension services, crop insurance, improved storage, and modern technologies further support adaptation. Together, these integrated strategies can boost productivity, reduce climate risks, protect natural resources, and promote sustainable agriculture for future generations.

Keywords: Climate change; Climate-smart agriculture; Climate-resilient crops; Water-use efficiency; Soil health; Integrated pest management; Sustainable agriculture; Food security

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112. Simulating Drought Impacts on Proso Millet (*Panicum miliaceum* L.) using DSSAT: A Review

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Abstract: One of the most critical abiotic factors affecting the crop production in the changing climate is drought stress, especially in arid and semi-arid areas like Pakistan where unreliable precipitation and water scarcity pose food insecurity and rural livelihood risks. Proso millet (*Panicum miliaceum* L.) is a short duration C4 cereal with 60-90 days maturity period and can be planted in non-irrigated arid lands with an annual precipitation of 200-500mm. The crop performance was stable in rainfed field trials in northern Italy, with an average water use efficiency corresponding to 1.83 kg m-3, thus confirming its potential as a water-saving crop. But the drought response is variable depending on intensity, duration and stage of growth, and it is estimated that the impact of water stress at early emergence is about 40% grain yield loss. The interactive effects of weather, soil, genotype and management at locations and seasons cannot be captured in field experiments. Crop models based on the process are suitable tools that can provide a powerful alternative simulation of crop growth, soil water balance, and yield under contrasting drought scenarios. For example, the CERES-Millet model was able to simulate days to flowering and days to maturity with RMSE lower than 2 days and grain yield in millet varieties in Niger with RMSE lower than 100 kg ha^{-1}. This review brings together the current knowledge about the proso millet adaptation to drought stress and its morphological, physiological and yield responses and critically assesses the potential of DSSAT for drought stress simulation, calibration and evaluation requirements, input data needs and limitations due to the lack of proso-millet specific genetic coefficients and experimental datasets. The research gaps are highlighted and an integrated research strategy is suggested where controlled drought experiments and crop modeling are integrated to better predict yield and risk. Integration can help inform evidence-based, climate-resilient agronomic decisions and aid in sustainable food security in water-constrained areas.

Keywords: Proso millet, *Panicum miliaceum*, Drought stress, DSSAT, Crop modeling, Climate-smart agriculture, Food security

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113. Tillage Practices affect Rhizospheric Moisture Availability and Performance of Chickpea (*Cicer arietinum* L.) Cultivars under Spate Irrigation in Punjab, Pakistan

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Abstract: Selection of suitable tillage techniques can ensure most productive use of available hill torrent water in spate irrigated areas for improved crop productivity and profitability. During rabi season 2021-22, a field study on chickpea was undertaken in Vidor hill torrent command area of Dera Ghazi Khan Punjab, Pakistan. In this experiment three cultivars of chickpea viz Bittle-2016, Thal-2020 and Bhakhar-2011 were evaluated under spate irrigated conditions along with local cultivar (Farmer practice) for comparison. Tillage practices at the seedbed preparation stage evaluated were cultivator and rotavator as follows i.e. T1= Two turns of cultivator (Farmer practice), T2=Three turns of cultivator, T3=Two turns of cultivator + one turn of rotavator, T4= one turn of cultivator + one turn of rotavator. The experiment was conducted under randomized complete block design (RCBD) with factorial arrangement and treatments were replicated three times. Soil moisture was measured through gravimetric method and chickpea yield parameters were estimated as per standard procedures. The means were tested for significance using HSD Tuckey's test at 5 % level of probability. Results revealed that cultivars and tillage practices showed significant variations for tested parameters. In this experiment maximum soil moisture conservation, number of branches per plant, pods per plant, seeds per pod, seed yield (kg ha-1) and harvest index (%) observed from Farmer practice i.e. 2 turns of cultivator under local cultivar used. Moreover, comparatively similar results were revealed from the plots where 3 turns of cultivator was run and Thal-2020 cultivar was grown under the local conditions of Vidor hill torrent command area of Dera Ghazi Khan, Punjab, Pakistan. Plots where 2 turns cultivator were used, the maximum benefit cost ratio (BCR, 1.85) was observed from local cultivar (Farmer practice). Moreover, among newly tested cultivars, Thal-2020 showed encouraging results in terms of soil moisture contents, yield attributes with BCR 1.73 in plots where 2 turns cultivator was run. Under the prevailing agro normals of spate irrigated conditions of Vidor hill torrent command area, farmers should use 2 turns of cultivator with local cultivar. However, more research is needed to acclimatize the latest varieties of chickpea after adaptability trials.

Keywords: Benefit-cost ratio, Chickpea, Tillage, Cultivars, Rotavator, Soil moisture conservation, Spate irrigation, Vidor hill torrent, Yield

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114. Role of Silicon in Improving Drought Tolerance in Maize

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Abstract: Maize (*Zea mays* L.) is one of the most important cereals for food, feed and industries, but in arid and semi-arid regions, recurrent drought leads to significant adverse effects on plant water status, photosynthetic capacity and grain production. Silicon (Si) is beneficial in improving the stability of the membranes, antioxidant defense, osmotic adjustment and water-use efficiency under drought stress, and its supplementation via seed priming and foliar application could be a complementary protection. Therefore, a field experiment was conducted at the Research Farm of MNS-University of Agriculture, Multan, Pakistan, during spring 2026 in a Randomized Complete Block Design with three replications. The treatments were T1 (normal irrigation), T2 (drought), T3 (hydropriming + drought), T4 (3 mM Si priming + drought), T5 (6 mM Si priming + drought), T6 (1 mM foliar Si + drought), T7 (hydropriming + foliar Si + drought), T8 (3 mM Si priming + foliar Si + drought) and T9 (6 mM Si priming + foliar Si + drought). Drought was imposed by withholding irrigation at 50% tasseling, and cob length, cob diameter, kernel rows per cob, cob weight, kernels per cob and kernel weight per cob were recorded. Treatments differed significantly ($P \leq 0.05$) for cob length, cob diameter, cob weight and kernel weight, but not for kernel rows or kernels per cob. The combined application of 6 mM Si priming and foliar Si (T9) gave the highest cob length (22.0 cm), cob diameter (18.0 cm), cob weight (302.7 g), kernels per cob (755.3) and kernel weight (243.3 g), exceeding the drought control (T2) by 13.8, 12.5, 29.7, 18.9 and 25.4%, respectively. Integrating Si seed priming with foliar Si is therefore a promising strategy to sustain cob development and yield attributes of maize under drought.

Keywords: Drought stress; Foliar silicon; Hydropriming; Maize; Seed priming; Silicon