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YELLOW MOSAIC DISEASE IN MUNGBEAN (*Vigna radiata*): RECENT ADVANCES AND EMERGING STRATEGIES FOR DISEASE MANAGEMENT

Narendra Kumar, Shilpa Dhaka, Sandeep Kumar, Everest Shiwach¹,
Nupur Prasad, Suman Verma and Punjab Singh Malik*

Plant Molecular Biology Lab, Department of Botany, Meerut College, Meerut, Uttar Pradesh 250001, India

¹Department of Botany, DN PG College, Meerut, Uttar Pradesh 250001, India

*Corresponding Author Email-punjabmalik@gamil.com

Abstract

Mungbean yellow mosaic virus (MYMV) disease is one of the most destructive diseases affecting mungbean and has been a significant concern in India. This disease is caused by a group of geminiviruses belonging to the genus Begomovirus within the family Geminiviridae. MYMV is transmitted persistently by the whitefly vector, *Bemisia tabaci*. Economic losses caused by this virus can reach up to 85% in green gram crops, and the disease continues to spread rapidly into new cultivation areas. The increasing impact of MYMV has driven the need for precise detection and identification methods, prompting extensive research on the virus's biology, diversity, and epidemiology to develop effective management strategies. Among control options, breeding for resistance or tolerance remains the most promising, yet currently available commercial varieties offer only partial resistance. Consequently, intensified efforts to discover new sources of resistance are essential. This review compiles the existing knowledge on MYMV and highlights critical areas where advanced research is urgently needed..

Key Words: Begomoviruses, *Mungbean yellow mosaic virus*, mungbean, *Bemisia tabaci*

Introduction

Vigna radiata (L.) Wilczek, commonly known as green gram or mungbean, is a vital legume crop originating from India or the Indo-Burmese region. It is extensively cultivated across Asia, Australia, the West Indies, the Americas, and tropical to subtropical regions of Africa. Adaptable to diverse cropping systems, mungbean plays a crucial role in cereal-based diets worldwide, covering over six million hectares annually. Asia alone accounts for approximately 90% of global mungbean production, with India being the largest producer, contributing about 65% of global acreage and 54% of total production (Karthikeyan et al, 2014; Singh, 2011). Nutritionally, mungbean are rich in carbohydrates (51%), proteins (24-26%), minerals (4%), and vitamins (3%). Additionally, its symbiotic relationship with root rhizobia

facilitates biological nitrogen fixation, enhancing soil fertility.

Despite its importance, mungbean yields remain low worldwide, averaging around 384 kg/ha, primarily due to biotic stresses such as insects, weeds, and diseases. Among pathogens, viruses, particularly begomoviruses transmitted by the whitefly *Bemisia tabaci*, represent the most significant threat to mungbean cultivation. Mungbean yellow mosaic disease (MYMD) is caused by bipartite begomoviruses including *mungbean yellow mosaic virus* (MYMV), *mungbean yellow mosaic India virus* (MYMIV), and *horse gram yellow mosaic virus* (HgYMV). These viruses are widely distributed across South and Southeast Asia, including India, Sri Lanka, Pakistan, Bangladesh, Papua New Guinea, the Philippines, and Thailand (Honda et al., 1983;

Varma et al., 1992; Haq et al., 2011).

The characteristic symptoms of MYMD begin with yellow specks along leaf veins, progressing to extensive chlorosis over the leaf lamina. Infected plants often develop thin, curled pods, leading to significant yield reductions of up to 85% (Varma and Malathi, 2003) (Fig 1). Despite numerous management strategies targeting MYMD, no commercially available mungbean cultivars possess complete resistance. The persistent vulnerability of mungbean to MYMD continues to threaten the crop's economic viability across the Asian subcontinent. This review synthesizes current understanding of MYMD and underscores the urgent need for intensified research aimed at developing durable resistance and integrated disease management strategies.



Fig 1: Symptomatology of *Mungbean yellow mosaic India virus* (MYMIV) infection in mungbean plants under field conditions.

Biology and Epidemiology of MYMIV

Begomoviruses were originally thought to have a single genomic component DNA-A, with DNA-B considered a satellite rather than an essential part of the genome (Briddon et al., 2010). However, later research confirmed that DNA-B is a critical component of bipartite begomoviruses such as *Mungbean yellow mosaic India virus* (MYMIV), and that both DNA-A and DNA-B evolved through the exchange and diversification of genomic segments. On the sense strand of DNA-A, the virus

encodes the coat protein (AV1) and a movement or pre-coat protein (AV2). The AV2 protein in MYMIV notably influences the activity of the replication-associated protein (Rep) by shifting the ratio of open circular to supercoiled DNA. The complementary strand encodes four proteins: Rep (AC1), transcription activator protein (AC2), replication enhancer protein (AC3), and AC4, which plays a role in symptom development. Additionally, AC5, located downstream of AC3, acts as a pathogenicity factor by suppressing sense-RNA-induced gene silencing (Li et al., 2015).

DNA-B carries two genes essential for viral movement: BV1 on the sense strand encodes the nuclear shuttle protein (NSP), and BC1 on the complementary strand encodes the movement protein (MP). The NSP mediates transport of viral DNA between the nucleus and cytoplasm and supports systemic movement, while the MP facilitates cell-to-cell transport through plasmodesmata (Cayalvizhi et al., 2015). In monopartite begomoviruses, these functions are largely replaced by the coat protein. A conserved 200-base pair common region (CR) shared between DNA-A and DNA-B contains the origin of replication (ori), marked by a stem-loop structure with a conserved nonanucleotide motif (TAATATT?AC) and iterons (Hanley-Bowdoin et al., 1999; Pant et al., 2001). These iterons serve as Rep binding sites to initiate rolling-circle replication and ensure coordinated replication of both components. Specific intron sequences—such as GGTGT in MYMIV, MYMV, and DoYMV—prevent interspecific recombination, while variants like GGTAT in HgYMV contribute to species-specific replication (Fig 2). Despite these barriers, occasional recombination events, including ori replacement, have been reported (Mishra et al., 2020).

MYMIV is transmitted primarily by the whitefly *Bemisia tabaci* in a persistent circulative manner and also through grafting, but not by sap, seed, or soil (Fig 3). The virus has a short latent period in the vector, and transmission can occur after only 15 minutes of feeding. Both male and female whiteflies are capable of transmission,

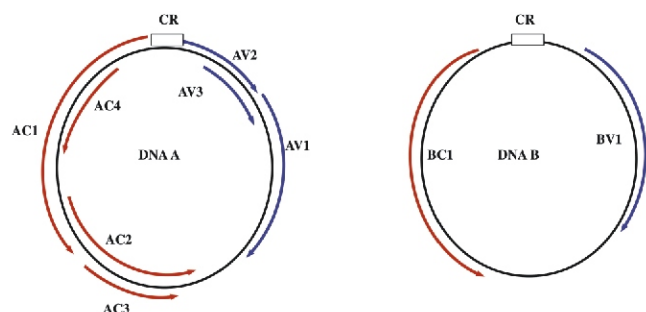


Fig 2: Genomic organization of *Mungbean yellow mosaic India virus* (MYMIV).

though females are significantly more efficient, remaining infectious for up to ten days compared to about three days for males. While nymphs can acquire the virus, there is no evidence of transmission through whitefly eggs. Disease incidence is closely linked to environmental conditions, with whitefly populations peaking during hot and humid summer months and decreasing during cooler seasons. The highest infection rates are typically observed when mungbean plants reach 45 days of age, coinciding with vector population peaks 20-30 days after sowing. Although mechanical transmission was once reported using phosphate buffer, subsequent studies have failed to replicate this, and sap-based transmission remains ineffective under experimental conditions (Verma and Malathi 2003; Malathi and Jone 2008a; Mishra et al., 2020).

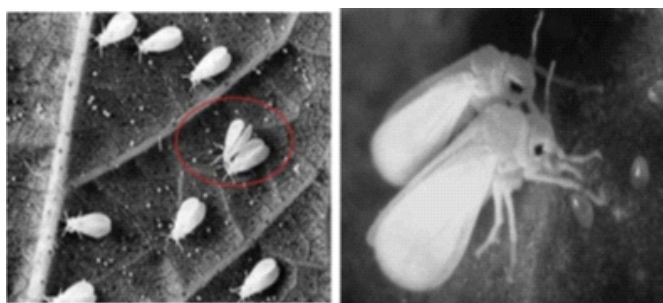


Fig 3: The begomovirus vector- whitefly (*Bemisia tabaci*) (adapted from Karthikeyan et al. 2014)

Source of Inoculum for Disease Development

Mungbean yellow mosaic virus (MYMV) infection is most detrimental when it affects the crop during early growth stages, often leading to substantial yield losses (Verma and Malathi 2003). Since commercially available mungbean cultivars with resistance to MYMV are limited, managing the primary inoculum sources becomes essential in controlling disease spread. Perennial weeds and summer-active whitefly populations are suspected to serve as early-season reservoirs of the virus, although their exact epidemiological roles remain under investigation (Malathi and John 2008b; Ilyas et al. 2009; Akthar et al. 2011; Ara et al. 2012). Effective whitefly management strategies depend on accurate identification of these inoculum sources. Elevated temperatures during summer tend to favour whitefly reproduction and survival, which correlates with increased MYMV incidence during this period. Infected but tolerant mungbean plants may also pose a risk by acting as silent carriers, allowing the virus to persist and potentially adapt against host resistance. Several cultivated legumes-including mungbean, urdbean, mothbean, pigeonpea, soybean, cowpea, and common bean-are considered agriculturally important MYMV hosts. Additionally, certain wild leguminous species such as *Vigna hainiana* and *Vigna trilobata* in India have been identified as natural MYMV hosts, emphasizing the potential for virus survival and spread through alternative reservoirs in the environment (Karthikeya et al., 2014).

Options for disease management

Strategies for managing mungbean yellow mosaic virus (MYMV) generally involve a combination of approaches, including the cultivation of resistant or tolerant varieties, effective control of the whitefly vector, elimination or management of alternate weed or crop hosts that can harbor the virus, and the adoption of agronomic practices that reduce conditions favourable for disease development (Karthikeya et al., 2014; Mishra et al., 2020)

Vector Management

Effective management of whiteflies, the primary vector of MYMV, is crucial for disease control, though it remains a complex challenge due to their rapid multiplication and infestation in large swarms. Even a single attack can significantly weaken the host plant. While cultural, mechanical, botanical, and chemical strategies exist, chemical control remains the most widely adopted method (Madhumitha et al., 2024). Systemic insecticides such as acetamiprid, ethion, imidacloprid, and triazophos have proven effective, acting both on contact and systemically within the plant, offering protection for extended periods. These insecticides are particularly effective against the early nymphal stages, which are more vulnerable, though poor coverage on the undersides of leaves where nymphs reside often leads to reduced field efficacy. Targeted application, especially on the leaf undersides, significantly improves control and yield, as demonstrated by studies like Ghosh (2008). Botanical alternatives such as neem seed kernel extract (NSKE) and neem oil foliar sprays also disrupt nymph development and reduce whitefly populations (Dubey et al. 2011). Additionally, integrated vector management practices such as maintaining field hygiene by removing weeds and crop residues, hand removal of heavily infested leaves, and applying water sprays to dislodge adults can help limit infestation. Reducing the use of nitrogen-rich fertilizers is also advised, as lush growth tends to attract more whiteflies. Employing environmentally friendly and sustainable methods alongside chemical strategies offers a more balanced and long-term approach to whitefly management and MYMV control.

Breeding for Resistance

Breeding for resistance to Mungbean Yellow Mosaic Virus (MYMV) has been a central strategy for disease management since the 1970s. Host plant resistance remains one of the most effective, economical, and environmentally sustainable methods for controlling MYMV. Plant responses to infection vary, with susceptible genotypes supporting virus replication and spread, while

resistant ones limit these processes. Resistance is often inferred from symptom expression, although some asymptomatic lines may still be infected, complicating selection. Screening of germplasm helps identify resistance or tolerance levels, which vary widely among mungbean lines. Resistance has been identified using standardized disease severity scales, though the effectiveness of resistance can differ depending on viral strain diversity (Marappa et al. 2003; Peerajade et al. 2004; Iqbal et al. 2011; Panduranga et al. 2011). Inheritance of resistance has been reported as controlled by single recessive, dominant, or multiple recessive genes, and both intra- and interspecific hybridizations have led to the development of resistant and high-yielding lines. However, resistance breakdown due to evolving virus strains and increased whitefly populations remains a challenge, making it necessary to integrate conventional breeding with modern approaches for durable resistance development (Mishra et al, 2020).

Marker-Assisted Selection (MAS)

The advent of DNA markers such as RFLP, RAPD, ISSR, SSR, and SNP has revolutionized plant genetics and breeding, particularly through their application in marker-assisted selection (MAS), a powerful tool for developing resistant cultivars (Laosatit et al., 2020). MAS allows breeders to identify plants carrying specific resistance genes or QTLs based on their genotype rather than relying solely on phenotypic traits, thus accelerating the selection process. Molecular markers have been instrumental in assessing genetic diversity, identifying markers linked to MYMV resistance genes, and constructing QTL maps, thereby enhancing the precision and efficiency of resistance breeding programs. Studies have successfully used various markers to tag MYMV resistance genes in mungbean, and MAS has already shown notable success in improving MYMV resistance (Chen et al., 2013). Additionally, novel resistance sources, including those from interspecific crosses, have been identified, and new molecular markers linked to resistance genes are becoming increasingly available (Sudha et al. 2013a). These genotypes

are now being evaluated for their effectiveness in providing durable resistance against dominant strains of both MYMV and MYMIV in highly affected hotspot regions.

Pathogen-based Resistance Strategy

Various transgenic strategies have been developed to engineer virus resistance in crops, with pathogen-derived resistance (PDR) emerging as one of the most effective approaches. In the absence of inherent resistance in commercial mungbean cultivars, researchers have turned to PDR-based transgenic methods. Initially proposed by Sanford and Johnston (1985), PDR involves the expression of viral genes—such as coat protein (CP), replicase, protease, or movement protein (MP)—within the host plant to disrupt key viral processes and induce resistance. This strategy has been successfully implemented across multiple crops, with outcomes ranging from delayed symptom expression and reduced viral load to near-complete immunity. For instance, expressing full-length or truncated replication initiation protein (Rep) genes from MYMV in transgenic tobacco inhibited viral replication effectively (Shivaprasad et al. 2006). Gene silencing mechanisms, including antisense RNA and post-transcriptional gene silencing (PTGS), have also been used to achieve resistance without expressing functional viral proteins. In mungbean, co-inoculation with anti-Rep constructs significantly reduced symptom severity and infection rates (Haq et al. 2010), and similar approaches using coat protein hairpin (Cphp) constructs further demonstrated effective resistance (Kumari and Malathi 2012). Moreover, agroinoculation techniques have proven useful in screening mungbean germplasm for resistance to different MYMV isolates, revealing a few genotypes with consistent resistance among a diverse set of lines. These findings highlight the potential of transgenic and molecular approaches

in strengthening mungbean resistance to MYMV (Sudha et al. 2013b; Karthikeyan et al. 2011).

Status and Emerging Challenges in the Management of Virus MYMV

Since the 1960s, evidence indicates a gradual expansion in both the diversity of mungbean cultivars and the geographical spread of Mungbean Yellow Mosaic Virus (MYMV) disease, particularly in regions like India, where agricultural intensity has risen to meet growing population demands. MYMV epidemics result from a complex interaction between the host plant, the virus, and environmental conditions, with outbreaks occurring only when all three factors align favorably (Singh et al. 20014). Thus, disease management strategies focus on disrupting this triad to hinder virus replication, survival, or infection. Despite efforts, most observed resistance in mungbean is tolerance, manifesting as mild symptoms rather than complete immunity. While improved lines like NM 92 and NM 94 released by AVRDC have shown resistance, they remain seasonally vulnerable, underscoring the instability of current resistance sources. Contributing factors include increasing disease pressure and whitefly populations (Nair et al., 2017). Traditional breeding approaches continue to investigate varietal responses in the field, but understanding the molecular interactions of the virus and developing resistance to emerging strains remain key challenges. Vector management, though conceptually promising, has proven difficult to implement effectively and does not strongly select for more virulent virus strains, making it relatively low risk. Recent advancements in molecular techniques such as marker-assisted selection (MAS) and genetic engineering offer promising avenues for enhancing MYMV resistance, though further research is necessary to fully realize their potential in disease management (Karthikeyan et al., 2014; Prema and Rangaswamy, 2018).

Future Research Direction

A primary objective in classifying MYMV strains is to understand their genetic diversity for both basic and applied research. However, a globally accepted and standardized system for differentiating MYMV strains is still lacking, leading to inconsistencies and confusion in resistance breeding programs (Meti et al., 2017). This lack of uniformity hampers the effective identification and exchange of resistance sources and germplasm. A consistent differential system is essential for identifying virus strains and enabling global collaboration among researchers. Moreover, understanding the pathogen's population structure across diverse geographical regions is necessary to build a comprehensive virus isolate database, which can guide strategic deployment of resistant genes and improve breeding efforts (Meti et al., 2017).

Although mungbean genome research has made progress, it lags behind other legumes like soybean, cowpea, and even its less economically significant relative, azuki bean. Marker systems such as RFLPs, RAPDs, AFLPs, SSRs, and ISSRs have been developed to facilitate marker-assisted selection (MAS) for MYMV resistance, yet none provide complete linkage coverage across all 11 mungbean chromosomes. Most genetic mapping efforts rely on markers from related legumes, which are often not tightly linked to resistance traits or lack proper validation. Therefore, developing and validating closely linked molecular markers, especially using resources like expressed sequence tags (ESTs) and SNP-rich genomic databases from related species, is critical (Karthikeyan et al., 2014). These tools would enable the identification of quantitative trait loci (QTLs) responsible for MYMV resistance and help in cloning resistance genes. Furthermore, creating near-isogenic lines (NILs) from residual heterozygote lines (RHLs) is recommended to validate QTLs, as resistance is often difficult to evaluate under field conditions.

MYMV resistance breeding in mungbean has primarily focused on race-specific resistance involving major resistance (R) genes, many of which are derived from exotic germplasm.

However, introgressing traits from wild relatives often results in undesirable agronomic characteristics that mask beneficial QTLs. To address this, the advanced backcross QTL (AB-QTL) method offers a more effective approach by allowing the simultaneous discovery and transfer of useful traits from wild species into elite cultivars (Sai et al., 2017). This strategy has been successful in many crops and holds promise for MYMV resistance in mungbean. Additionally, transgenic approaches have shown potential, including the use of coat protein (CP) genes, agroinoculation for screening, and RNA interference (RNAi) to engineer resistance. Although these methods have shown promise, more extensive research is needed. Ultimately, developing MYMV-resistant mungbean varieties is essential for stable crop production. (Mishra et al., 2020). While traditional methods have had limited success due to the emergence of new virus strains and complex resistance mechanisms, modern molecular genetics, when combined with conventional breeding, offers a powerful toolkit for combating MYMV and ensuring long-term resistance (Zaidi et al., 2016).

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OPTIMIZING CULTIVATION OF PLEUROTUS ERYNGII THROUGH ENVIRONMENTAL CONDITION MODELLING: EFFECTS ON YIELD AND EFFICIENCY

Himanshu*, Prashant Kumar, Jitendra Kumar, Sandeep Kumar, Everest Shiwach¹,
Nupur Prasad, Narendra Kumar and Punjab Singh Malik*

Department of Botany, Meerut College, Meerut, Uttar Pradesh, India

¹ Department of Botany, DN PG College, Meerut, Uttar Pradesh, India

*Corresponding Author Email- himanshutaliyan@gmail.com, punjabmalik@gmail.com

Abstract

Pleurotus eryngii is a mushroom forming saprophyte belonging to *Basidiomycetes*. Its survival and multiplication are influenced by different environmental factors such as temperature, relative humidity, fresh air, light and CO₂ concentration which may act individually or synergistically. Therefore, suitable technology for successful cultivation of King Oyster mushroom needs to be standardized. Based on these factors, three environmental conditions models – 1, 2, and 3 were innovated in present study. These environmental condition models were used for cultivation of two strains – DMRP-120 and DMRP-135 of *P. eryngii*. Three substrates i.e. – paddy straw + sawdust, sugarcane bagasse + sawdust and sawdust alone were used to carry out the experiments during the study. The results revealed that sawdust and environment conditions model -1 were found to be the best and resulted in maximum yield on sawdust followed by paddy straw and sugarcane bagasse in combination with sawdust. As compared to model-1, 12-22% low productivity was observed on sawdust combination substrate under environmental conditions models 2 and 3. The environmental conditions model-1 provided following congenial environmental factors- temperature – 24 ±2°C (Spawn Running), 17-18±2°C (Pin head or Primordia Formation), 14-16±2°C (Fresh fruiting body for harvest); humidity – 90-95% (SR), 85-90% (PF), and 70-75% (FBH); CO₂ concentration (ppm) 5000- 20,000 (SR), <1000 (PF), and <1000 (FBH); Fresh air (hrs. /day) – nil (SR), 4-5 (PF), and 5-6 (FBH); and Light (hrs. /day) – nil (SR), 3-4 (PF) and 4-5 (FBH) for achieving higher productivity. Therefore, these standardized environmental conditions models with congenial environmental factors are crucial to boost up commercial production by growers for achieving higher quality and productivity of king oyster mushrooms.

Key Words: Environmental conditions, *P. eryngii*, Substrates, Biological efficiency.

Introduction

Pleurotus eryngii is also known as King oyster mushroom and is native to Mediterranean region of Europe, Middle East and North Africa but also grown in many parts of Asia including India. It has been considered as an important food and generally cultivated for its taste, nutritional value and biologicals (Ryu et al., 2006; Sharma et al., 2018). This mushroom has also been used for medicinal purposes particularly to manage Type-2 diabetes due to low calories, high fibre and

digestibility (Kim, 2010). The fungus requires colder environment for completing its production cycle. It has harder skin for longer shelf life and normally cultivated on woods and sawdust at 19 – 20°C temperature under natural climate during autumn and spring season of different regions of European Union Countries (Dias, 2010; Szarvas et al., 2010; Sharma et al., 2017; Bellettini et al., 2019). Production of *P. eryngii* mushroom on different agro-wastes substrates and under varying environmental conditions have been

reported by different workers (Moonmoon et al., 2010; Bellettini et al., 2019; Jezenabadi et al., 2016; Karthick and Hamsalakshmi, 2017; Deora et al., 2021). In India, *P. eryngii* mushroom is being cultivated on different substrates at 15 – 21°C temperature and 85 – 95% humidity in short day conditions but cultivation could not be exploited at commercial scale by farmers so that the contribution of this speciality mushroom is less than 1% of total production of 1.5 lakh tonnes of all kind of mushrooms produced (Sharma et al., 2017; Deora et al., 2021). King oyster mushroom is a saprophytic weak parasite grown on different agro-wastes having lignocellulosic organic matters and its survival and multiplications are influenced with different environmental factors – temperature, humidity, CO₂ concentration, fresh air and light which may act as individually or synergistically in their regulatory function during mushroom cultivation.

Optimal growth and fruiting of *P. eryngii* require precise environmental control, which significantly influences biological efficiency, yield, and quality. Traditional cultivation methods often fail to achieve consistent results due to fluctuating climatic conditions and non-standardized practices. Therefore, applying environmental condition modelling to simulate and control growth conditions presents a promising strategy to improve productivity and crop uniformity.

This study aims to evaluate the impact of different environmental condition models on the yield and biological efficiency of *P. eryngii*. By systematically analyzing growth performance under varied temperature, humidity, and light regimes, we aim to identify optimal cultivation parameters that maximize output and enhance the commercial viability of *P. eryngii* cultivation. The findings are expected to contribute to the development of climate-resilient, year-round mushroom production systems tailored for diverse agro-ecological zones.

Materials and Methods

Based on the different environmental conditions three environmental conditions models -1, 2, and 3 were innovated by using integrated approach of environmental factors – temperature (°C), humidity(%), CO₂ concentration (ppm), fresh

air (hrs./day) and light (hrs./day) as per the requirement of three phases – spawn running, pin head formation, and fruiting body development of production cycle of *P. eryngii* mushroom for achieving higher productivity of better quality marketable grade mushrooms (Table 1). Two authentic strains of *P. eryngii* DMRP – 120 and DMRP – 135 were collected from Directorate of Mushroom Research, Solan, Himachal Pradesh for conducting experiments. Three innovated environmental conditions models – 1, 2 and 3, and three substrates - sugarcane bagasse +sawdust (SB+SD), paddy straw +sawdust (PS+SD) and sawdust (SD) were used for conducting experiments. The data helped us to assess the efficacy of these models. The substrate suitability was also analyzed for the excellent qualitative growth from spawn running to fresh harvesting fruiting body, with distinct morphological characters and biological efficiency of *P. eryngii* mushroom for higher productivity.

Substrate Sterilization

Three types of prepared substrate - sugarcane bagasse +sawdust (1:1), paddy straw +sawdust (1:1) and sawdust alone were used for mushroom cropping cycle. A total of 60 bags were prepared with each type of substrate composition. Thus, for three models, a total of 180 bags were used for mushroom cultivation. The experiments were completed in three successive years 2019-2021. A total of 60 bags (year wise) for each model in three successive years were sterilized in an autoclave at 121°C for 90 minutes and then allowed to cool down at room temperature for overnight.

Spawn Production

Spawn was prepared using wheat grains as substrate briefly, wheat grains were boiled and glass bottles were filled with boiled wheat grains with 1% CaCO₃ (w/w). The bottles were sterilized at 121°C for 1.5 hrs. in an autoclave and cooled at room temperature for overnight. The sterilized bottles were inoculated with two pieces of mycelium agar plugs (1 cm diameter) taken from the advance margin of 5-8 days old colony of *P. eryngii* on MEA (malt extract agar) medium. The inoculated bottles were incubated at 25°C±2°C until the completion of mycelium growth in bottles.

Crop production cycle of *P. eryngii*

The sterilized bags marked for each model were transferred to mushroom growth chamber as per the environmental conditions mentioned for model -1, 2, and 3 in successive years – 2019-2021 and arranged according to *P. eryngii* strains – DMRP-120 and DMRP-135 separately for conducting experiments. The bags were then inoculated inside a laminar air flow chamber using 5-6% optimum grain spawn (weight basis).

Table 1: Environmental Conditions Models for the cultivation of *Pleurotus eryngii*

Environmental factors	Growing Condition Phase		
	Spawn running	Pin head or Primordia formation	Fresh fruiting body for harvest
Model - 1			
Temperature	24° ± 2°C	17-18°C	14 – 16°C
Humidity	90-95%	85-90%	70 – 75 %
CO₂ concentration	High 5000-20000 ppm	Low <1000 ppm	Low <1000 ppm
Fresh air	Nil/No	4 – 5 hrs.	5 – 6 hrs.
Light	No	3 – 4 hrs.	4 – 5 hrs.
Model - 2			
Temperature	22°C ± 2°C	14° - 16°C	12° - 14° C
Humidity	85 – 90 %	80 – 85%	65 -70 %
CO₂ concentration	Low 4000-18000 ppm	Low <800 ppm	Low <800 ppm
Fresh air	Nil	2 – 3 hrs.	3 – 4 hrs.
Light	Nil	2 – 3 hrs.	3 – 4 hrs.
Model – 3			
Temperature	26° ± 2°C	20 – 22° C	18 – 20°C
Humidity	95 – 100%	90 – 95 %	75 – 80%
CO₂ concentration	High 7000-22000 ppm	High <1200 ppm	High <1200 ppm
Fresh air	Nil	5 – 6 hrs.	6 – 7 hrs.
Light	Nil	4 – 5 hrs.	5 – 6 hrs.

After completing the inoculation, the environment conditions were maintained as above for different models (model -1, 2, and 3) in three successive years during the crop cycle from spawn running to fresh fruiting body ready for harvest. The cotton plugs and polypropylene bags were removed after mycelia stimulation and spawn running. The mushroom productivity of both strains DMRP-120 and DMRP-135 was evaluated accordingly to the duration of crop production cycle – mycelia stimulation and spawn running (days), spawn running to pin head formation (days), pin head to fresh fruiting body for harvest (days) and biological efficiency under the three environmental conditions models. The biological efficiency was determined as per following formula (Tsegaye and Tafera, 2017)-

$$BE = \frac{\text{fresh weight of the mushroom}}{\text{Dry weight of the substrate}} \times 100$$

Dry weight of the substrate

The weight of three flushes was measured separately of each bag and accounted total weight was used for calculating the biological efficiency. The data were analysed by calculating mean and standard error for both the strains and environmental conditions models -1, 2, and 3. The additional informations on different variables were also recorded like – no. of pinheads, weight of fruiting body, size of

mushroom, size of cap and any disease appearance /damage on each substrate under environmental conditions models -1, 2, and 3 for the productivity of both strains of *P. eryngii*.

Results

Effectiveness of substrates and environmental conditions models on growth and productivity of *P. eryngii*

Substrates and environmental conditions are essential factors involved in *P. eryngii* mushroom cultivation. These factors influence the production and quality parameters of mushroom. In present study, three substrate formulations, three environmental conditions models -1, 2 and 3; and two strains DMRP-120 and DMRP-135 were tested to assess their efficacy for achieving higher yield and production with enhanced morphological characters of *P. eryngii* mushrooms. The qualitative growth of both the strains of *P. eryngii* on sawdust was observed from spawn running -35.65 days (DMRP-120) and 36.35 days (DMRP-135) to pin head formation -7.45 days (DMRP-120) and 8.25 days (DMRP-135), and fresh fruiting body for harvest- 8.56 days (DMRP-120) and 12.75 days (DMRP-135). The total period of production process was 51.66 days (DMRP-120) and 57.35 days (DMRP-135) on sawdust. This was followed by 37.26 days (DMRP-120) and 38.26 (DMRP-135) days, 8.50 days (DMRP-120) and 9.75 days (DMRP-135) and 9.25 days (DMRP-120) and 12.98 days (DMRP-135) for spawn running, pin head formation and fresh fruiting body ready for harvest, with the total period of 55.01 days (DMRP-120) – 60.99 days (DMRP-135) for production process on paddy straw + sawdust combination respectively under environmental condition model-1 (Table 2 and 3). The primordia formation appeared normal and healthy up to 7.26-8.26 in numbers on paddy straw + sawdust, and sawdust substrates in both the strains. The complete fruiting bodies for harvest were developed within an average period of 8.56–12.95 days. The morphological characters were also recorded – weight 210.60 – 226.50g (DMRP-120) and 180.65 – 214.50g (DMRP-135) with mushroom size – 3.50 – 5.75 inches (DMRP-120) and 3.43 – 5.10 inches (DMRP-135) and cap size 1.34–1.50

inches (DMRP-120) and 1.12 – 1.39 inches (DMRP-135) with ideal consistency and qualitatively market grade mushrooms. However, a reduction up to 7.11-8.35% was observed in morphological characters –weight, size of mushroom and cap size in both the strains grown on sugarcane bagasse and paddy straw in combination with sawdust.

Further, the regulation of environmental factors of cultivation protocol models influenced the crop production process. The crop production period increased as 60.05 days (DMRP-120) and 62.55 days (DMRP-135) under environmental conditions described in model -2 on sawdust. Accordingly, the production process period decreased up to 43.24-45.93 days (DMRP-120) and 43.01 – 42.66 days (DMRP-135) under environmental conditions in model – 3 for both the strains on all the three substrates, as compared to 51.66-58.28 days (DMRP-120) and 57.35-62.70 days (DMRP-135) of crop production process was observed in model-1.

When environmental conditions described in model-2 were applied, the mycelium growth appearance was delayed up to 2-5 days for multiplication in both the strains under model-2 as compared to model -1, so that spawn-running was completed within a period of 37.25-39.95 days with slow growth. After spawn-running and opening of the bags, the early appearance of primordia was also delayed due to the low temperature – temperature 14-16°C, RH 80-55%, CO₂ concentration < 800 mg/Kg and applying fresh air and light 3-4 hrs./day. More pinheads developed under these conditions actually created problems in thinning. Therefore, fewer numbers (3-4) of primordia were selected for further growth of fruiting bodies. The complete fruiting bodies (ready for harvest) got developed in a longer time (12-15 days) and took more time like 60.05–67.18 days (DMRP-120) and 62.55-69.82 days (DMRP-135) to complete the production process.

Influence of environmental conditions models on morphological characters of *P. eryngii*

The morphological characters were also found to be affected more in model -3 as compared to model-1 and 2. The mycelium multiplication for

spawn-running on sawdust was recorded as normal at 26°C with 95-100%RH and CO₂ concentration in the dark without fresh air. However, poor puffy cottony growth of mycelium of DMRP-120 was observed on paddy straw + sawdust and sugarcane bagasse + sawdust substrates. Whereas the same trend, as 2-3 days early appearance of mycelium was observed in the DMRP-135 strain so this strain seems to have little heat tolerance. After spawn-running and bag opening, pin heads developed prominently in an average number of 3.40-4.52 (DMRP-120) but the fruiting body developed were less in weight varied from 165.36-185.89g. The fruiting bodies were exponentially elongated (4.95-6.35inches) with flat cap (1.45-1.65 inches) in DMRP-120 strain of *P. eryngii*. However, size and cap were found in more elongated and flattened form in the DMRP-135 strain of *P. eryngii* (Tables –4 and 5). Moreover, stipe with thickness was also observed with the reduction of weight (10%) of the fruiting body, size of mushroom (23%) and cap (18.23%).

Table 2: Growth development cycle (days) of *Pleurotus eryngii* strain DMRP -120 under different environmental conditions models

Substrate	Spawn running (days) / (SE)	Pin head Formation (days)/(SE)	Fresh harvest (days)/(SE)
Model -1			
SB + SD	38.13 (0.02)	9.56 (0.05)	10.59 (0.06)
PS+ SD	37.26 (0.03)	8.50 (0.03)	9.25 (0.03)
SD	35.65 (0.02)	7.45 (0.03)	8.56 (0.04)
SD (control)	36.30 (0.02)	7.60 (0.04)	8.9 (0.02)
Model - 2			
SB + SD	39.95 (0.04)	11.67 (0.02)	15.56 (0.02)
PS + SD	37.25 (0.03)	10.37 (0.04)	12.55 (0.03)
SD	38.25 (0.03)	9.10 (0.02)	12.70 (0.03)
SD (control)	38.35 (0.02)	8.90 (0.03)	12.86 (0.02)
Model - 3			
SB + SD	32.65 (0.03)	6.35 (0.04)	6.93 (0.02)

PS + SD	31.86 (0.03)	6.30 (0.02)	6.84 (0.02)
SD	29.89 (0.02)	6.40 (0.02)	6.95 (0.03)
SD (control)	30.56 (0.05)	6.50 (0.02)	7.34 (0.03)

Table 3: Growth development cycle (days) of *Pleurotus eryngii* strain DMRP - -135 under different environmental conditions models

Substrate	Spawn running (days) / (SE)	Pin head Formation (days)/(SE)	Fresh harvest (days)/(SE)
Model -1			
SB + SD	38.32 (0.02)	10.63 (0.05)	13.75 (0.02)
PS + SD	38.26 (0.04)	9.75 (0.02)	12.98 (0.03)
SD	36.35 (0.02)	8.25 (0.02)	12.75 (0.03)
SD (control)	37.60 (0.03)	8.46 (0.03)	12.85 (0.02)
Model - 2			
SB + SD	41.37 (0.02)	12.65 (0.05)	15.80 (0.02)
PS + SD	40.58 (0.04)	8.25 (0.03)	15.23 (0.03)
SD	39.25 (0.02)	9.35 (0.03)	13.95 (0.03)
SD (control)	39.67 (0.03)	9.56 (0.06)	14.59 (0.04)
Model - 3			
SB + SD	28.37 (0.03)	6.25 (0.03)	7.10 (0.04)
PS + SD	28.29 (0.03)	5.85 (0.03)	6.98 (0.03)
SD	29.00 (0.05)	6.30 (0.02)	7.36 (0.03)
SD (control)	29.79 (0.04)	6.10 (0.03)	7.12 (0.04)

Yield and Biological Efficiency of *Pleurotus eryngii* strains grown under different environmental conditions models

The significantly higher yield of 810.75-880.65g/Kg (DMRP-120) and 809.25-880.50g (DMRP-135) and biological efficiency 81.07-88.06% (DMRP-120) and 80.92-88.05% (DMRP-135) of both the strains – DMRP-120 and DMRP-135 were obtained under

the environmental conditions described in model-1. Simultaneously, average growth productivity and biological efficiency were also analysed -yield 778.56 g/Kg (13% low), BE 77.85%, (DMRP-120) and yield 767.50 g/Kg (13.7% low), BE 76.75% (DMRP-135) in cultivation protocol model-2. Whereas, yield as 685.65g/Kg, BE 68.56% (25% low) (DMRP-120) and yield 652.50 g/Kg BE 65.25% (25.95% low) (DMRP-135) were recorded in model-3 on sawdust. The productivity and biological efficiency were poor on paddy straw + sawdust and sugarcane bagasse + sawdust as compared to sawdust in model – 2 & 3.

Table 4: Morphological characteristics of *P. eryngii* strain DMRP – 120 under different environmental conditions models

Substrate	Growth Characters	Number of pin heads	Weight of fruiting body (g)	Size of mushrooms (inches)	Size of cap (inches)
Model -1					
SB + SD	Normal	7.30 (0.03)	219.50 (0.03)	3.50 (0.04)	1.12 (0.04)
PS + SD	Normal	7.26 (0.02)	210.60 (0.05)	4.26 (0.03)	1.34 (0.03)
SD	Normal	8.90 (0.02)	226.50 (0.03)	5.75 (0.02)	1.49 (0.02)
SD (control)	Normal	8.26 (0.03)	225.35 (0.02)	5.73 (0.03)	1.50 (0.02)
Model -2					
SB + SD	Normal delay	6.28 (0.03)	186.45 (0.02)	3.25 (0.03)	1.05 (0.04)
PS + SD	Normal delay	6.69 (0.03)	190.35 (0.03)	3.67 (0.02)	1.25 (0.02)
SD	Normal	7.79 (0.02)	195.75 (0.04)	4.75 (0.04)	1.38 (0.02)
SD (control)	Normal	7.40 (0.02)	194.65 (0.05)	4.65 (0.05)	1.35 (0.03)
Model -3					
SB + SD	Poor growth	3.40 (0.03)	165.36 (0.04)	6.12 et (0.05)	1.50 ab (0.02)
PS + SD	Poor growth	4.50 (0.02)	180.56 (0.02)	4.95 et (0.03)	1.45 ab (0.04)
SD	More mycelium	4.52 (0.02)	185.89 (0.02)	6.35 et (0.02)	1.65 ab (0.02)
SD (control)	More mycelium	4.50 (0.02)	184.75 (0.03)	6.15 et (0.03)	1.55 ab (0.03)

et: etiolated, ab: abnormal

Table 5: Morphological characteristics of *P. eryngii* strain DMRP – 135 under different environmental conditions models

Substrate	Growth characters	Number of pin heads	Weight of fruiting body (g)	Size of mushrooms (inches)	Size of cap (inches)
Model -1					
SB + SD	Scanty Thin	7.29 (0.04)	199.00 (0.02)	3.43 (0.06)	1.12 (0.05)

PS + SD	Normal	6.35 (0.02)	180.65 (0.03)	4.25 (0.04)	1.25 (0.02)
SD	Normal	8.31 (0.03)	214.50 (0.04)	5.10 (0.02)	1.39 (0.03)
SD (control)	Normal	7.95 (0.02)	210.75 (0.02)	4.95 (0.02)	1.31 (0.03)
Model -2					
SB + SD	Normal delay	6.51 (0.02)	183.35 (0.03)	3.15 (0.02)	1.10 (0.03)
PS + SD	Normal delay	6.59 (0.03)	189.36 (0.04)	3.57 (0.03)	1.22 (0.02)
SD	Normal	7.25 (0.03)	194.65 (0.02)	4.65 (0.02)	1.37 (0.02)
SD (control)	Normal	7.13 (0.02)	193.25 (0.02)	4.35 (0.02)	1.33 (0.03)
Model -3					
SB + SD	Poor growth	3.40 (0.02)	178.05 (0.02)	6.13 et (0.03)	1.50 ab (0.03)
PS + SD	Poor growth	4.50 (0.03)	179.46 (0.04)	6.12 et (0.04)	1.41 ab (0.02)
SD	More mycelium	5.60 (0.03)	184.35 (0.02)	6.45 et (0.02)	1.55 ab (0.02)
i0SD (control)	More mycelium	5.60 (0.02)	183.46 (0.03)	6.35 et (0.03)	1.51 ab (0.02)

et: etiolated, ab : abnormal

Discussion

Globally, different workers in their previous studies have reported cultivation of *Pleurotus eryngii* mushroom on different substrates including agro and industrial wastes under different environmental conditions—temperature, relative humidity, CO₂ concentration, fresh air and light (Jamil et al., 2019; Flegg, 1968; Jeznabadi et al., 2016; Szarvas, 2014; Melanouri, 2022). These environmental factors may act individually or synergistically during different phases (spawn running, pinhead formation and fruiting body development) of the production cycle of mushrooms in controlled or natural conditions of tropical and subtropical areas (Dias, 2010).

Table 6: Variation in Biological Efficiency and Yield of King Oyster Mushroom Strain-120 under different environmental conditions models

Substrates	Mean of fresh weight of three flushes (g)	Biological efficiency (%)
Model-1		
Sugarcane bagasse + sawdust	810.75 (0.03)	81.07 (0.02)
Paddy straw +sawdust	816.69 (0.02)	81.66 (0.03)
Sawdust	880.65 (0.02)	88.06 (0.02)
Sawdust (control)	879.84 (0.02)	87.98 (0.02)
Model-2		
Sugarcane bagasse + sawdust	690.45 (0.04)	69.04 (0.03)
Paddy straw +sawdust	695.56 (0.02)	69.55 (0.02)

Sawdust s	778.56 (0.03)	77.85 (0.03)
Sawdust (control)	756.80 (0.02)	75.68 (0.02)
Model-3		
Sugarcane bagasse + sawdust	595.86 (0.03)	59.58 (0.02)
Paddy straw +sawdust	601.75 (0.02)	60.17 (0.02)
Sawdust	685.65 (0.02)	68.56 (0.03)
Sawdust (control)	625.35 (0.02)	62.53 (0.02)

Table 7: Variation in Biological Efficiency and Yield of King Oyster Mushroom Strain-135 under different environmental conditions models

Substrate	Mean of fresh weight of three flushes (g)	Biological efficiency (%)
Model-1		
Sugarcane bagasse + sawdust	809.25 (0.02)	80.92 (0.03)
Paddy straw +sawdust	810.56 (0.03)	81.05 (0.04)
Sawdust	880.50 (0.03)	88.05 (0.02)
Sawdust (control)	872.50 (0.02)	87.25 (0.02)
Model-2		
Sugarcane bagasse + sawdust	682.75 (0.04)	68.27 (0.02)
Paddy straw +sawdust	688.48 (0.03)	68.84 (0.03)
Sawdust	767.50 (0.02)	76.75 (0.02)
Sawdust (control)	756.54 (0.03)	75.65 (0.02)
Model-3		
Sugarcane bagasse + sawdust	597.75 (0.03)	59.77 (0.04)
Paddy straw +sawdust	599.65 (0.02)	59.96 (0.03)
Sawdust	652.50 (0.02)	65.25 (0.02)
Sawdust (control)	636.25 (0.02)	63.62 (0.02)

Under the current scenario of *P. eryngii* cultivation under different environmental conditions, suitably advanced technology for the successful cultivation of King Oyster mushrooms is needed to be standardized to achieve higher productivity both qualitatively and quantitatively. Therefore, the aim of our present study was to test three environmental conditions models -1, 2 and 3 by using an integrated approach of different environmental factors as per the requirements of different phases (spawn running, pin head formation, and fruiting body development) for the production cycle of *P. eryngii* mushroom.

The three environmental conditions models -1, 2 and 3, two strains - DMRP-120 and DMRP-135 of *P. eryngii* and three substrate formulations- paddy straw + sawdust (1:1), sugarcane bagasse + sawdust (1:1) and sawdust were used to conduct experiments to evaluate their efficacy for achieving the qualitatively higher productivity with refined morphological characters. The results authenticated that environmental conditions of model -1 have been proved potentially the best among three for cultivation of *P. eryngii* strains. This model resulted in higher productivity during the crop production process on sawdust followed by paddy straw and sugarcane bagasse. Moreover, both the strains – DMRP-120 and DMRP-135 have completed their production cycle within a short period of 51.66-58.28 days and 57.35 -62.70 days with an average period of spawn running (38.45 days), pinhead formation (8.25 days) and fruiting body for harvest (226.50g in 8.56 days). However, the DMRP-135 strain grew slowly by taking 5.69 days more time to complete the production cycle on sawdust with low weight (214.50g) of the fruiting body. The morphological characters were also observed such as marketable high grade fruiting body with excellent texture and consistency, mushroom weight, size and cap size in both the strains. Our results obtained in the present study, under model -1 were found comparatively better than the results reported by earlier workers in their studies in relation to production cycle period, yield and morphological characters (Flegg, 1968; Ryu et al., 2006; Szarvas, 2014; Bandura et al., 2022; Dias, 2010, Jamil et al., 2019; and Melanouri et al., 2022). Also, during environmental conditions model-2, the change in environmental factors effect was directly correlated with mushroom productivity. The production cycle period of both strains was increased for each substrate with the appropriate change of environmental factors. The pin head developed in equal numbers at low temperatures (14-16°C) and the size of the fruiting body was shorter with thickened stipe with a small cap and less weight. Similar observations were also obtained at variable environmental conditions– 15-22°C, RH 88-100%, and CO₂ concentration of 1100 ppm by Dias, 2010; Moonmoon, 2010; and Bandura et al., 2022. Simultaneously, levels of environmental factors in model-3 influenced the productivity by

minimizing the period up to 10-15days of the production process of both the strains with low yield and abnormal morphological characters as puffy and poor mycelium growth at 26°C, a smaller number of primordia (3-5), mushroom weight (165.36-185.89g), elongated mushroom size (4.95-6.35 inches) with abnormal margin. In addition, some fruiting bodies were found to bend towards light at variable temperatures (18-22°C). This observation has also been reported by Jennings and Lysek, 1999 that the stipe grows towards the light source during primordia growth of *Pleurotus eryngii* of *Basidiomycetes*. All three environmental conditions models -1, 2 and 3 were also assessed on their performance in relation to yield and biological efficiency, which was directly influenced by low and high environmental condition parameters. The maximum yield (880.65 and 880.50 g/Kg) and biological efficiency (88.06% and 88.05%) were obtained in model-1 on sawdust. There was a decrease in yield and BE under environmental conditions models-2 and 3 respectively on sawdust. The present study was done for the results-oriented standardization of environmental conditions models- 1, 2 and 3 for higher productivity. It is evident that environmental conditions model-1 described congenial environmental factors for obtaining higher productivity of good quality mushroom of *Pleurotus eryngii*.

Conclusion

The present study demonstrates that environmental condition modelling significantly influences the yield and biological efficiency of *Pleurotus eryngii*. Among the different environmental setups evaluated, specific combinations of temperature, relative humidity, and light intensity were found to markedly enhance both yield and biological efficiency, indicating the species' strong responsiveness to controlled cultivation parameters. These findings underscore the importance of precise environmental management in mushroom farming, particularly for commercially valuable species like *P. eryngii*.

By optimizing growth conditions, cultivators can achieve higher productivity, better resource utilization and improved economic returns. The

study also provides a framework for environmental standardization in mushroom cultivation, potentially supporting year-round production and scaling under variable climatic zones. Future research should focus on integrating additional factors to further refine the cultivation model and promote sustainable mushroom farming practices.

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INFLUENCE OF GIBBERELIC ACID AND NAPHTHALENE ACETIC ACID ON FRUIT RETENTION, YIELD AND QUALITY PARAMETERS OF AONLA

Ayushi Shrivastava, V. K. Tripathi* and Akhilesh Mishra**

Department of Fruit Science

**Legume Section

C.S. Azad University of Agriculture and Technology, Kanpur-208 002(U.P.), India

*Corresponding Author Email-drvkttripathicsa@gmail.com

Abstract

An experiment was carried out in the Horticulture Garden of C. S. Azad University of Agriculture and Technology, Kanpur (U.P.) during 2023, using nine treatments viz., GA₃ at 20 and 50ppm, NAA at 15 and 30ppm along with their combinations including a control (water spray) on twenty-six years old plant of aonla cv. NA-7 replicated thrice in Randomized Block Design. From the experiment, it is reported that higher concentration of GA₃ @ 50 ppm + NAA @ 30 ppm significantly reduced fruit drop (18.84%) and increased fruit retention (81.16%). It also gave maximum fruit yield (211kg/plant), increased fruit length (3.74cm), fruit width (4.97cm), fruit weight (30.02g), fruit volume (27.79cc), specific gravity (1.08g/cc), pulp weight (28.68g) and maximum pulp: stone ratio (21.41). Plants treated with GA₃ @ 50ppm + NAA @ 30ppm also resulted in an increase in ascorbic acid (605.49mg/100g), TSS (12.15°Brix) and total sugar (9.81%) content. GA₃ @ 50ppm + NAA @ 30ppm significantly reduces the stone weight (1.34g) and acidity (1.72 %) under the plains of northern India.

Key Words: Aonla, Gibberellic acid, NAA, Fruit retention, Yield and Quality

Introduction

The Indian gooseberry (*Emblica officinalis* Gaertn L.), also known as aonla, is a significant fruit found in arid tropical regions and has significant medicinal and nutritional benefits, belongs to the family Euphorbiaceae. Aonla is particularly valued for its high vitamin C content, far exceeding many other fruits and vegetables. Additionally, it contains significant amounts of dietary fiber, which aids digestion, and various minerals that contribute to overall health. Intensive aonla plantation is being done in the salt-affected districts of Uttar Pradesh, including ravine areas of Agra, Mathura, Etawah, Fatehpur and semi-arid tracks of Bundelkhand. Aonla cultivation is also spreading rapidly in the semi-arid regions of Maharashtra, Gujarat, Rajasthan, Andhra Pradesh, Karnataka, Tamil Nadu and Aravali ranges in Haryana and Kandi

area in Punjab and Himachal Pradesh. As per recent estimates, aonla has spread over 91,000 ha in the country with an approximate production of 9.8 lac tonnes (Anonymous 2018).

Fruits are commonly used for making preserves (Murabba), pickles, candy, jelly, sauce, dried chips, etc. In respect of nutritional values, it is a rich source of vitamin C (500-750 mg/100g). In the Ayurvedic system which includes Trifla, Chyavanprash and Amrit Kalash, are mostly prepared from aonla fruits. The foliar application of plant bio-regulators has an immensely important role in improving fruit set, productivity and quality of fruits. GA₃ and NAA have been found more effective in improving flowering, fruit set, fruit drop, fruit size, fruit maturation, fruit yield and fruit quality of aonla.

NAA increases the TSS, possibly due to the auxin synthesis in plants. It increases the

physiological activities leading to increased TSS in fruits, while the total sugars increase might be due to the activation of enzymes which affect the physiological processes, which in turn hydrolyzed the starch and helps in metabolic activity during the change in available starch into sugar and soluble solid content (Ghosh *et al.*, 2009), keeping these all in view, an experiment was carried out to investigate the effect of foliar application of GA₃ and NAA on fruit retention, yield and quality parameters of aonla under north Indian Conditions.

Materials and Methods

An experiment was laid out in 2023 on the twenty-six years old plant of aonla cv. NA-7, in the garden of the Department of Horticulture, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur (U.P.) was selected for the present investigation. Geographically, Kanpur district falls in a subtropical zone with hot dry summer and severe cold in winter. The physico-chemical composition of soil shows that it is sandy loam in texture with good organic matter content, slightly acidic (pH 6.5) in nature, well-drained and contains 65.33% sand, 22.33% silt and 12.34% clay.

Twenty-seven trees having uniform growth were selected randomly before foliar application of GA₃ and NAA. The standard cultural operations and basal application of manures and fertilizers were applied as per the recommended schedule for aonla plantation.

The nine treatments *viz.*, GA₃ at 20 and 50ppm, NAA at 15 and 30ppm along with their combinations of GA₃ @ 25 ppm + NAA @ 15 ppm), GA₃ @ 25 ppm + NAA @ 30 ppm), GA₃ @ 50 ppm + NAA @ 15 ppm and GA₃ @ 50 ppm + NAA @ 30 ppm including a control (water spray), replicated thrice in randomized block design were used to study their influence on fruit retention, yield and quality.

The spraying of GA₃ and NAA was done on 27th August and 19th October 2023 at the time of fruit bud developmental stage and fruit growth stage, respectively. Data were recorded at 15 day's intervals after foliar application till harvesting and harvesting was done on 6th December 2023. The observations were recorded on per cent fruit

drop and per cent fruit retention. The physical characters of fruits *i.e.* fruit size (length and width of fruits), weight, fruit volume (cc), stone and pulp weight, pulp: stone ratio per cent, specific gravity, fruit yield and the chemical characters *i.e.* fruit moisture per cent, total soluble solids (TSS), titratable acidity, ascorbic acid (vitamin C) and total sugars content after harvest were studied as per method suggested in (AOAC, 1990). The experimental data were analysed statistically with analysis of variance method given by Panse and Sukhatme (1985).

Results and Discussion

Fruits Drop and Retention per cent

In the present study, it was observed that significantly reduced fruit drop and higher fruit retention percentage were observed in the plants treated with the combination of GA₃ and NAA (Fig. 1 and 2). Application of GA₃ @ 50ppm + NAA @ 30ppm (T₈) resulted in a significant reduction in fruit drop (18.84%) with higher fruit retention (81.16%) closely followed by GA₃ @ 50ppm + NAA @ 15ppm (24.14% and 75.86%, respectively), whereas, the maximum fruit drop (61.26%) and minimum fruit retention (38.74%) percentage was recorded under control. The beneficial effect of NAA application in reducing fruit drop and increased retention percentage may be explained by the fact that it maintains the ongoing physiological and biochemical process of inhibition of abscission (Ghosh *et al.* 2009) this may also be due to a weakening and ultimate fracturing of the middle lamella of cell in or near the abscission layer and low amount of auxin. Various workers have also been reported to reduced fruit drops in different fruit crops such as Lal *et al.* (2015) in Kinnow, Tripathi *et al.* (2019) in mango and Badal and Tripathi (2021) in guava.

Fruit Yield

The foliar application of plant bio-regulators and micronutrients treatments significantly increased the fruit yield per plant as compared to control. Foliar application of T₈-GA₃ @ 50 ppm + NAA @ 30 ppm in combination recorded maximum yield (211 kg/plant), followed by T₇-GA₃ @ 50ppm + NAA @ 15ppm with 203 kg/plant, T₆-GA₃ @ 25ppm + NAA @ 30ppm with 197 kg/plant, T₅-GA₃ @

25ppm + NAA @ 15ppm with 192 kg/plant of fruit yield. In contrast, minimum fruit yield (144 kg/plant) was observed in plants under control (Fig. 3). The combined use of GA₃ and NAA can synergistically affect the fruit yield of aonla. GA₃ promotes fruit growth and fruit set, while NAA prevents fruit drop, substantially increasing overall yield. The results of the present investigation support the findings of Tiwari *et al.* (2017) in aonla, Tripathi *et al.* (2018) and Tripathi *et al.* (2022) in aonla.

Fruit Length and Width

In the present investigation, fruit size (length and width) was significantly increased with the combined foliar application of GA₃ and NAA (Table 1). Plants received a foliar application of T₈-GA₃ @ 50ppm + NAA @ 30ppm produced fruits having maximum length and width (3.74 and 4.97cm, respectively) followed by T₇-GA₃ @ 50ppm + NAA @ 15ppm noted 3.65 and 4.97cm, respectively, T₆-GA₃ @ 25ppm + NAA @ 30ppm noted 3.62 and 3.95cm, respectively, T₅-GA₃ @ 25ppm + NAA @ 15ppm noted 3.55 and 3.78cm, respectively. In comparison, the control group of plants produced the lowest fruit length and width, measuring 3.26 and 3.22cm, respectively. When nutrient concentration decreases, there is a significant reduction in fruit length and width. The application of GA₃ and NAA enhances the transportation of nutrients from the production site to the storage organs, leading to an increase in fruit length and width. The current study's results align with earlier studies on various fruits, such as in aonla cv. Francis Singh *et al.* (2007), Tripathi *et al.* (2018) and Chaudhary *et al.* (2018) in aonla cv. NA-7 Shukla *et al.* (2011), in strawberry cv. Chandler Tripathi and Shukla (2008) in kinnow mandarin Lal *et al.* (2016).

Fruit Weight and Volume

Fruit weight and volume were significantly influenced by the combined foliar application of GA₃ and NAA (Table 1). Significantly higher weight (30.02g) and Volume (27.79 cc) were recorded in fruits treated with T₈-GA₃ @ 50ppm + NAA @ 30ppm followed by the application of GA₃ @ 50ppm + NAA @ 15ppm having weight (29.13 g) and Volume (27.19 cc). It is also observed that with the reduction in the dose of plant bio-regulators,

weight and volume of fruits also get reduced but remain significant as compared to the control, which produced minimum fruit weight (25.17g) and volume (25.02 cc). It could be because GA₃ increases cell proliferation and food material transfer, possibly boosting fruit weight. The effect of GA₃ and NAA spray fruit weight increased because plants got more food and energy from photosynthesis. This may have led to faster production of metabolites, especially carbohydrates, and transport of those metabolites to fruit, which increased the pulp content. These findings match those of Gupta *et al.* (2022) in litchi, Badal and Tripathi (2021) in guava and Tripathi and Viveka Nand (2022) in aonla, Tiwari *et al.* (2017) in aonla.

Fruit Specific Gravity

The foliar application of GA₃ and NAA significantly impacted the specific gravity of produce (Table 1). The plant that received a dosage of T₈-GA₃ @ 50 ppm + NAA @ 30 ppm resulted in the highest specific gravity (1.08g/cc) followed by T₇-GA₃ @ 50ppm + NAA @ 15ppm resulted (1.07 g/cc). In contrast, we recorded that untreated plant resulted in the lowest specific gravity of 1.00 g/cc. This increase in specific gravity with the application of GA₃ and NAA might be due to the rise in fruit pulp and decrease in stone weight. These findings match those research studies by Tripathi *et al.* (2019) in mango, Tiwari *et al.* (2017) in aonla.

Fruit Pulp Weight

Significantly more weight of pulp (28.68 g) with reduced stone weight (1.34g) was recorded in the fruits which were harvested from the plants treated with the T₈-GA₃ @ 50 ppm + NAA @ 30 ppm followed by T₇-GA₃ @ 50ppm + NAA @ 15ppm which resulted in 27.65 g of pulp and 1.48 g of fruit stone weight, whereas, fruits with minimum pulp weight (23.01 g) and maximum stone weight (2.16g) were found in untreated control plant. Remaining all other treatments also significantly increased pulp content in the fruits as compared to control (Table 1). This increase in fruit pulp weight with the application of NAA might be due to the direct involvement of auxin in the acceleration of biochemical activity in plant parts and the translocation of mineral nutrients during the

process of fruit development. The results are in accordance with the findings of Singh and Singh (2015), Bhadauria *et al.* (2018) and Tripathi and Vivekanand (2022) in aonla. The effect of GA₃ enhances metabolism, which reduces stone size; also, GA₃ can increase sink demand. Certain enzymes, such as invertase cell wall-bound in the core and invertase neutral and NAD-dependent sorbitol dehydrogenase on the pulp, are believed to activate this increase; such enzymes play a crucial role in the growth of fruit. These results are consistent with the findings of Gupta *et al.* (2022) in litchi, Kumar *et al.* (2018) in mango, Chandra *et al.* (2015), Bhadauria *et al.* (2018) in aonla.

Pulp: stone ratio

The foliar application of GA₃ and NAA significantly affected the fruit pulp ratio (Table 1). The plant received T₈-GA₃ @ 50 ppm + NAA @ 30 ppm produced fruits with the highest fruit pulp: stone ratio (21.41), followed by T₇-GA₃ @ 50ppm + NAA @ 15ppm noted (18.46), T₆-GA₃ @ 25ppm + NAA @ 30ppm noted (16.66), T₅-GA₃ @ 25ppm + NAA @ 15ppm noted (15.36) pulp: stone ratio. At the same time, control resulted in the lowest fruit pulp: stone ratio (10.65). The acceleration of biochemical activities and accumulation of metabolites in plant parts may be the cause of the increased pulp: stone ratio. This is probably due to PGRs and micronutrients working synergistically to convert and translocate total sugar and minerals during the fruit development and maturation processes. These results are consistent with the studies carried out by Kumar *et al.* (2018) in mango, Singh *et al.* (2007), Tiwari *et al.* (2017) and Bhadauria *et al.* (2018) in aonla.

Total Soluble Solids and Total Sugars

Maximum total soluble solids and total sugars content (Table 2) were recorded with the foliar application of T₈-GA₃ @ 50ppm + NAA @ 30 ppm (12.15°Brix and 9.81%, respectively) followed by T₇-GA₃ @ 50ppm + NAA @ 15ppm (11.97°Brix and 9.65%, respectively), whereas, the minimum total soluble solids and total sugars content were recorded in untreated plants (9.80°Brix and 7.23%, respectively). GA₃ indirectly influences many enzyme systems in plants, out of these the role of gibberellins in the activation of amylase enzyme is

well known which are responsible for the conversion of starch into sugar thus improve the TSS and total sugars contents in fruits. Gibberellins are known to play a crucial role in the sugar metabolism of plants. Notably, research has shown that NAA significantly boosts the sugar and soluble solid content in aonla fruit. NAA, being an auxin, also promotes cell division and expansion, improving nutrient uptake and metabolism. These changes collectively contribute to higher sugar accumulation in the fruit. The results are in accordance with the finding of Kumar and Tripathi (2009) in strawberry, Badal and Tripathi (2021) in guava, Singh and Singh (2015), Tiwari *et al.* (2017) in aonla.

Titrateable acidity

The results clearly showed that the plant treated with T₇-GA₃ @ 50ppm + NAA @ 15 ppm respectively had the minimum (1.72%) titrateable acidity, followed by T₈-GA₃ @ 50ppm + NAA @ 30ppm recorded (1.74%), whereas untreated plant had the maximum (1.97%) titrateable acidity (**Table 2**). Plant growth regulators (PGRs) can potentially increase fruit quality by reducing acidity, which is essential for flavour perception and consumer satisfaction. Two ways can explain such a reduction in acidity; one way is the sugar and derivatives undergo a reverse glycolytic pathway, which leads to the decomposition of acidic components, resulting in more accumulation of sugars. Secondly, PGRs can stimulate vegetative growth in plants, thereby diverting the metabolic pathways towards non-pH-dependent changes, which would reduce or nearly restore acidity within fruits. The results are consistent with the research by Yadav *et al.* (2010), Singh and Singh (2015), Shukla *et al.* (2011) in aonla.

TSS: acid ratio:

The foliar application of GA₃ and NAA significantly affected the TSS: acid ratio (Table 2). Plant treated with T₈-GA₃ @ 50ppm + NAA @ 30ppm recorded highest (6.98) TSS: acid ratio, followed by T₇-GA₃ @ 50ppm + NAA @ 15ppm noted (6.95), T₆-GA₃ @ 25ppm + NAA @ 30ppm noted (6.70), T₅-GA₃ @ 25ppm + NAA @ 15ppm noted (6.32) TSS: acid ratio, whereas untreated plant

resulted lowest (4.97) TSS: acid ratio. GA₃ and NAA have been observed to influence the TSS content in aonla fruit positively. Applying these PGRs enhances the sugar content, resulting in higher TSS values. However, these PGRs typically result in a decrease in the acidity of aonla fruits. This reduction in acidity, coupled with an increase in TSS, improves the TSS: acid ratio. A higher ratio is desirable as it indicates a better balance of sweetness and acidity. Studies have shown that the combined application of GA₃ and NAA significantly improves the ratio, enhancing fruit quality. The results are consistent with the research by Shrivastava *et al.* (2009) and Chaudhary *et al.* (2018) in aonla.

Ascorbic acid

Vitamin-C is a powerful antioxidant and is an important part of human feed. It helps to save the human from many serious diseases and scavenges the reactive oxygen species (ROS) produced in the body. The maximum ascorbic acid contents (605.49mg/100g) were recorded in the fruits produced from the plants treated with T₈-GA₃ @ 50ppm + NAA @ 30ppm closely followed by T₇-GA₃ @ 50ppm + NAA @ 15ppm (602.02mg/100g) treated plants, which is higher than remaining all other treatments (Table 2), whereas, the minimum ascorbic acid content was obtained in untreated control plants (581.09mg/100g). The application of these PGRs is believed to influence various biochemical pathways that increase the production of ascorbic acid. GA₃ promotes cell elongation and division, which can enhance the overall metabolic activity of the fruit, including ascorbic acid synthesis. NAA, being an auxin, also promotes cell division and expansion, contributing to increased nutrient uptake and synthesis. The finding is in accordance with the results of Singh *et al.* (2007), Yadav *et al.* (2010), and Shukla *et al.* (2011) in aonla.

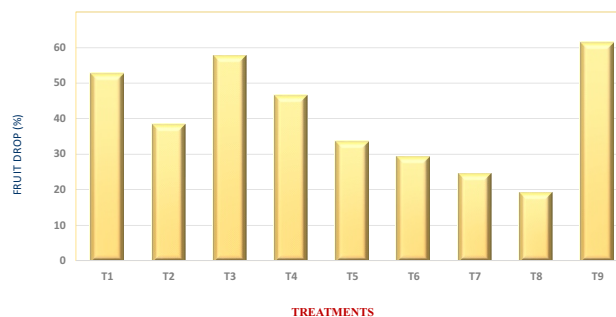


Fig. 1: Influence of Gibberellic acid and Naphthalene acetic acid on fruit drop percentage in aonla cv. NA-7

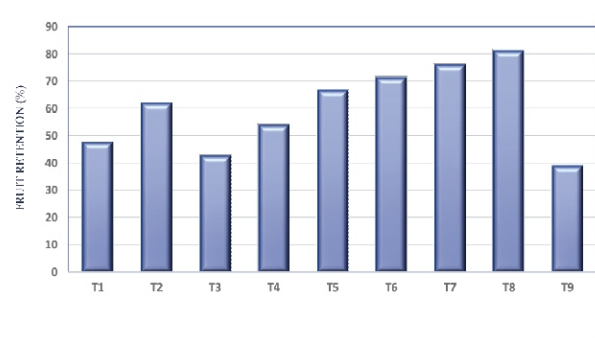


Fig. 2: Influence of Gibberellic acid and Naphthalene acetic acid on fruit retention percentage in aonla cv. NA-7

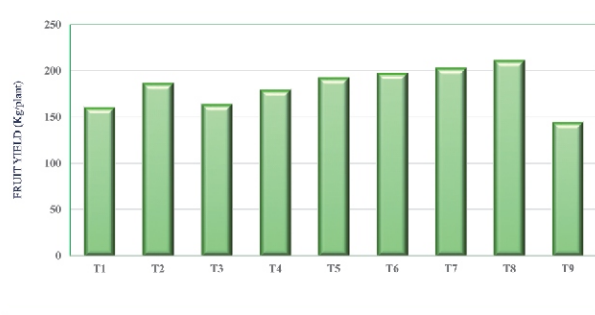


Fig. 3: Influence of Gibberellic acid and Naphthalene acetic acid on fruit yield (kg/plant) in aonla cv. NA-7

Table 1. Influence of Gibberellic acid and Naphthalene acetic acid on physical characters of fruits in aonla cv. NA-7

Treatments	Fruit length (cm)	Fruit width (cm)	Fruit weight (g)	Fruit volume (cc)	Specific gravity (g/cc)	Pulp weight (g)	Stone weight (g)	Pulp: stone ratio (%)
T1-GA3 @ 25ppm	3.49	3.41	25.75	25.01	1.02	23.69	2.06	11.51
T2-GA3 @ 50ppm	3.54	3.66	27.86	26.71	1.04	25.97	1.89	13.74
T3-NAA @ 15ppm	3.45	3.38	25.73	25.45	1.01	23.65	2.08	11.37
T4-NAA @ 30ppm	3.53	3.61	26.71	25.91	1.03	24.77	1.94	12.76
T5-GA3 @ 25ppm + NAA @ 15ppm	3.55	3.74	28.14	26.80	1.05	26.42	1.72	15.36
T6-GA3 @ 25ppm + NAA @ 30ppm	3.62	3.78	28.97	27.11	1.06	27.33	1.64	16.66
T7-GA3 @ 50ppm + NAA @ 15ppm	3.65	3.95	29.13	27.19	1.07	27.65	1.48	18.46
T8-GA3 @ 50ppm + NAA @ 30ppm	3.74	4.97	30.02	27.79	1.08	28.68	1.34	21.41
T9-Control (water spray)	3.26	3.22	25.17	25.02	1.00	23.01	2.16	10.65
S.E.(m) $\pm$	0.06	0.08	0.35	0.35	0.01	1.10	0.05	0.22
CD at 5% level	0.20	0.26	1.06	1.06	0.05	3.32	0.15	0.67

Table 2. Influence of Gibberellic acid and Naphthalene acetic acid on chemical composition of fruits in aonla cv. NA-7

Treatments	TSS (OBrix)	Total sugar (%)	TSS: acid ratio	Titrateable acidity (%)	Ascorbic acid (mg/100g pulp)
T1-GA3 @ 25ppm	10.51	8.15	5.97	1.76	584.22
T2-GA3 @ 50ppm	10.92	8.51	6.03	1.81	592.19
T3-NAA @ 15ppm	10.26	7.88	5.75	1.78	581.18
T4-NAA @ 30ppm	10.75	8.30	5.81	1.85	591.94
T5-GA3 @ 25ppm + NAA @ 15ppm	11.06	8.71	6.32	1.75	594.14
T6-GA3 @ 25ppm + NAA @ 30ppm	11.80	9.44	6.70	1.76	598.93
T7-GA3 @ 50ppm + NAA @ 15ppm	11.97	9.65	6.95	1.72	602.02
T8-GA3 @ 50ppm + NAA @ 30ppm	12.15	9.81	6.98	1.74	605.49
T9-Control (water spray)	9.80	7.23	4.97	1.97	581.09
S.E.(m) $\pm$	0.15	0.13	0.10	0.03	2.76
CD at 5% level	0.48	0.39	0.32	0.09	8.34

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EFFECT OF INTEGRATED NUTRIENT MANAGEMENT ON QUALITY TRAITS, ECONOMICS RETURNS AND SOIL NUTRIENTS AVAILABILITY AFTER HARVEST OF CARROT (*DAUCUS CAROTA* L.) IN ARID REGION

Prem lal Gadri¹, M. K. Poonia², Santosh Choudhary³,

Aditya Narayan Dadheech⁴, Ronak Kuri⁵

Agriculture University, Jodhpur (Rajasthan)-342 304

M.Sc. Researcher^{1*,4} Department of Horticulture, CoA, Jodhpur

²Professor Department of Horticulture, CoA, Sumerpur, Pali (Life member of society)

³Asst. Professor Department of Horticulture, CoA, Jodhpur

⁵Ph.D. Scholar Department of Horticulture, CoA, Jodhpur

*Corresponding Author Email-maheshkponia@gmail.com

Abstract

A field experiment was conducted at the Instructional Farm, College of Agriculture, Jodhpur, during the *Rabi* season of 2023-24 to evaluate the effect of integrated nutrient management on Quality Traits, Economics Returns and soil nutrients availability after harvest of carrot (*Daucus carota* L.) in arid region. The experiment consists of thirteen treatments conducted in Randomized Block Design (RBD) replicated thrice. Results revealed that effect of various nutrient combination had effect on Quality Traits and available nitrogen, phosphorus and potassium (Kg/ha). 100% RDF + *Azotobacter* + PSB + KSB (T₁₁) improved the maximum total soluble solids (9.60 °Brix), carotene content (4.92 mg/100g), chlorophyll content of leaves at harvest (1.098 mg/100g) and available nitrogen (183.68 Kg/ha), available phosphorus (23.35 Kg/ha) and available potassium (332.23 Kg/ha) contents in soil as compared to control (174.00, 21.01 and 320.33 Kg/ha, respectively).

Key Words: Recommended dose of fertilizer (RDF), *azotobacter*, phosphate solubilizing bacteria, potassium solubilizing bacteria

Introduction

Carrot (*Daucus carota* L.) is an important root vegetable, which belongs to the family Apiaceae with the diploid chromosome number $2n = 18$. It originated from South-West Asia and later on distributed throughout the China and the Mediterranean region. It is cultivated all over the world during spring-summer in temperate countries and winter in tropical and sub-tropical countries. It is an annual plant for root production but biennial for seed production. The edible part of carrot is a modified root (conical form) while inflorescence is a 'Compound Umbel' (Choudhary et al., 2023).

In India, carrot is cultivated in an area of 1.23 lakh ha with a production of 23.99 lakh tonnes (Anonymous, 2023). It is mainly cultivated in the states of Punjab, Haryana, Uttar Pradesh, West Bengal, Madhya Pradesh, Tamilnadu, Bihar and Rajasthan. In Rajasthan, carrot is cultivated in an area of 5.92 thousand ha with a production of 21.85 thousand tonnes. The major carrot growing districts are Jodhpur, Alwar and Sri Ganganagar.

Integrated nutrient management is an approach of supplying nutrition to the crop by including organic and inorganic sources of nutrients. Thus, a combined use of organic manures, biofertilizers with a reduced dose of chemical fertilizers, not only pave the way for

higher yield and quality produce but also help to maintain the soil health and reduce pollution problems (Shanu et al., 2019). Biofertilizers also an important component of organic sources in integrated nutrient management system which plays a major role in supplementing the crop nutrients through biological nitrogen fixation and solubilization of fixed forms of phosphorous in soil (Kumar et al., 2018). Biofertilizer is the microbial inoculants that contain the culture of dormant or live cells of the effective strains of N-fixing, P-solubilizing and mobilizing, and K-solubilizing (Fasusi et al., 2021). The microbial inoculants are also known to help in mobilizing available micronutrients in soil through secrete growth promoting substances. They are among the vital constituents of integrated nutrient management strategies for meeting both soil productivity and sustainability, at the same time keeping the environment safe, pollution-free and economic (Yadav and Sarkar, 2019).

Materials and method

The field experiment was conducted at the Instructional Farm, College of Agriculture, Jodhpur, during the Rabi season of 2023-24. Soil of the experimental field was sandy loam in texture, slightly alkaline in reaction, poor in organic carbon (0.13%), low in available N (170.2 kg/ha), medium in available P (20.2 kg/ha) and high in available K (318 kg/ha). Treatments comprised of thirteen treatment combination Control [RDF (60 kg N, 40 kg P₂O₅ and 120 kg K₂O/ ha)] (T1), 100% RDF + Azotobactor (T2), 75% RDN + full P and K + Azotobactor (T3), 50% RDN + full P and K+ Azotobactor (T4), 100% RDF + Phosphate Solubilizing Bacteria (PSB) (T5), 75% RDP + full N and K + Phosphate Solubilizing Bacteria (PSB) (T6), 50% RDP + full N and K + Phosphate Solubilizing Bacteria (PSB) (T7), 100% RDF + Potassium Solubilizing Bacteria (KSB) (T8), 75% RDK + full N and P + Potassium Solubilizing Bacteria (KSB) (T9), 50% RDK + full N and P + Potassium Solubilizing Bacteria (KSB) (T10), 100% RDF + Azotobactor + Phosphate Solubilizing Bacteria (PSB) + Potassium Solubilizing Bacteria (KSB) (T11), 75% RDF + Azotobactor + Phosphate Solubilizing Bacteria (PSB) + Potassium Solubilizing Bacteria (KSB) (T12) and 50% RDF + Azotobactor + Phosphate Solubilizing Bacteria

(PSB) + Potassium Solubilizing Bacteria (KSB) (T13) were tested in Randomized Block Design (RBD) with three replication

Data were recorded on quality parameters namely TSS (oBrix), carotene content (mg/100 g), chlorophyll content of leaves (mg/100 g) and soil parameter including available nitrogen in soil (kg/ha), available phosphorus in soil (kg/ha), available potassium in soil (kg/ha) and economics. After harvest of the crop, soil samples were collected from the random spots from each plot and then it was pooled to make a composite sample for soil testing, which was of about 500 g. Samples were oven dried at 65 °C till the constant weight was achieved. Available nitrogen, phosphorus and potassium were analyzed from the soil samples. Following methodologies and procedures were adopted for determination of soil-

Soil Parameters	Methods	References
Available N (kg/ha)	Alkaline KMnO ₄ method	Subbiah and Asija, 1956
Available P ₂ O ₅ (kg/ha)	Olsen's method	Olsen et al. 1954
Available K ₂ O (kg/ha)	Flame photometric Method	Jackson, 1973

Data were analyzed statistically for analysis of variance (ANOVA). Treatments were compared by computing the 'F-test'. The significant differences between treatments were compared by critical difference at 5% level of probability (Panse and Sukhatme, 1985).

Results and discussion

Quality parameters-

A perusal of data (Table-1) revealed that the application of plant nutrients through integrated nutrient management significantly affected the quality and soil attributes of radish. It is evident from the data that the application of 100% RDF + Azotobactor + Phosphate Solubilizing Bacteria (PSB) + Potassium Solubilizing Bacteria (KSB) (T11) resulted highest total soluble solids (9.60 oBrix), which was statistically similar to treatment T12 (75% RDF + Azotobactor + PSB + KSB). Increasing potassium fertilizer played a key role in raising the root TSS value. Higher nutrient dosages hastened metabolic activity in the shoot and accumulation of photosynthates, leading to increased storage of various carbohydrates,

predominantly sucrose. These findings align with Lyngdoh (2001), Roshani et al. (2019) and Shanu et al. (2019) in carrot.

The highest value of carotene content (4.92 mg 0 Brix) and chlorophyll content of leaves (1.098 mg/100g) was recorded in treatment T11 (100% RDF + Azotobacter + PSB + KSB), which was statistically similar to treatment T12 (75% RDF + Azotobacter + PSB + KSB). The maximum carotene content observed was due to the readily available major and minor nutrients, in line with the findings of Vithwel and Kanaujia (2013) in carrot, who reported that biofertilizers might activate specific enzymes for carotene synthesis. Similar results have been reported by Roshani et al. (2019) and Shanu et al. (2019) in carrot.

Total chlorophyll content in carrot leaves increased significantly due to integrated nutrient management. This increase in chlorophyll content can be attributed to higher nitrogen levels, as nitrogen is a constituent of chlorophyll. These results are comparable with the reports of Manjunatha (2003) in carrot, Choudhary et al. (2017) in knol-khol and Mali et al. (2018) in radish.

Soil parameters-

From the results of the present investigation (Table-2), it clearly shows that the highest amount of available nitrogen (183.68 kg/ha), phosphorus (23.35 kg/ha) and potassium (332.23 kg/ha) in the soil after harvest was obtained in the treatment T11 (100% RDF + Azotobacter + PSB + KSB) compare to other treatment. However, the initially available nitrogen, available phosphorus and available potassium available in soil before sowing was 170.2, 20.2 and 318 kg/ha, respectively, The immediate availability of nitrogen from chemical fertilizers to plants, combined with increased nitrogen fixation by biofertilizers, contributed to higher total nitrogen uptake and improved nitrogen availability to plants and soil. The increase in phosphorus content can be attributed to the solubilizing effect of organic acids produced by PSB, which convert insoluble phosphorus into soluble forms and reduce phosphorus fixation, thus enhancing phosphorus availability and absorption by plants. The availability of potassium in plants and soil is due to the production of organic acids and other chemicals that stimulate growth and mineral uptake. KSB release

potassium from insoluble potash minerals, increasing K availability in the soil. Similar findings were reported by Sugumaran and Janarthanam (2007) and Parmar and Sindhu (2013) in radish. These results are consistent with reports by Teja (2021) in radish and kumar Yogendra (2021) in cabbage.

Economics

From the present investigation (Table -3) it was found that the The highest net returns (? 2,69920.36/ha) were obtained with treatment T11 (100% RDF + Azotobacter + PSB + KSB), followed by treatment T12 (75% RDF + Azotobacter + PSB + KSB) with ? 2,68024.02/ha. The highest B: C ratio was observed in treatment T12 (75% RDF + Azotobacter + PSB + KSB) at 3.09: 1, followed by treatment T11 (100% RDF + Azotobacter + PSB + KSB) at 3.05: 1. These results closely align with previous findings by Kumar et al. (2013), Vithwel and Kanaujia (2013), Nisar et al. (2019) and Shanu et al. (2019) in carrot and Teja (2021) in radish.

Table : 1 Effect of integrated nutrient management on quality of carrot

S.N.	TSS (oBrix)	Carotene content (mg/100g)	Chlorophyll content of leaves (mg/100g)
T1	8.63	4.37	1.016
T2	9.36	4.77	1.083
T3	9.30	4.69	1.076
T4	8.80	4.41	1.024
T5	9.38	4.79	1.080
T6	9.32	4.72	1.074
T7	8.85	4.44	1.022
T8	9.40	4.82	1.078
T9	9.34	4.75	1.072
T10	8.88	4.47	1.020
T11	9.60	4.92	1.098
T12	9.52	4.89	1.093
T13	9.25	4.66	1.032
SEm±	0.11	0.08	0.014
CD (P =0.05)	0.31	0.24	0.041

Table : 2 Effect of integrated nutrient management on available soil parameters of carrot

S.N.	N (kg/ha)	P ₂ O ₅ (kg/ha)	K ₂ O (kg/ha)
T1	174.00	21.01	320.33
T2	181.58	22.64	327.67
T3	174.08	21.63	324.12
T4	172.14	21.38	322.86
T5	178.11	22.83	326.90
T6	176.26	21.10	323.46
T7	175.60	18.63	322.10

T8	177.58	22.53	328.91
T9	176.18	21.44	320.56
T10	175.06	21.22	319.06
T11	183.68	23.35	332.23
T12	174.71	21.17	321.86
T13	173.19	19.10	319.43
Initial value	170.20	20.2	318
SEm $\pm$	2.09	0.28	2.70
CD (P =0.05)	6.11	0.83	7.87

Table : 3 Effect of integrated nutrient management on economics of carrot

S.N.	Total cost	*Gross returns (?/ha)	Net returns (?/ha)	B:C Ratio
T1	83642.64	291180	207537.36	2.48:1
T2	85142.64	315484	230341.36	2.71:1
T3	84946.98	306536	221589.02	2.61:1
T4	84751.32	295228	210476.68	2.48:1
T5	85142.64	313616	228473.36	2.68:1
T6	84642.64	304268	219625.36	2.59:1
T7	84142.64	294168	210025.36	2.50:1
T8	85387.64	312276	226888.36	2.66:1
T9	84487.64	301048	216560.36	2.56:1
T10	83587.64	293428	209840.36	2.51:1
T11	88387.64	358308	269920.36	3.05:1
T12	86791.98	354816	268024.02	3.09:1
T13	85196.32	289876	204679.68	2.40:1

Conclusion

The study concluded that the maximum total soluble solids (9.60 °Brix), carotene content (4.92 mg/100g), chlorophyll content of leaves (1.098 mg/100g), available nitrogen (183.68 kg/ha), phosphorus (23.35 kg/ha), and potassium (332.23 kg/ha) in the soil after harvest were obtained with the application of 100% RDF + Azotobacter + PSB + KSB (T₁₁). The application of biofertilizers in combination with chemical fertilizers would aid to draw additional nutrients for better crop growth, quality traits and availability of nutrient under a long run would aid to a substantially sustainable soil health

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EFFECT OF GA₃ AND MICRONUTRIENTS ON FRUIT DROP, CRACKING AND QUALITY ATTRIBUTES OF LITCHI CV. DEHRADUN

Aradhana Verma, A. K. Singh**, V.K. Tripathi,

Somendra Verma* and Shiwanand Pandey

Department of Fruit Science

C.S. Azad University of Agriculture and Technology, Kanpur, 208002 (UP.)

**Directorate of Extension, C.S. Azad University of Agriculture and Technology, Kanpur-208002

*Corresponding Author Email-somendraverma56@gmail.com

Abstract

The study was conducted at the Horticulture Garden, Department of Fruit Science, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur. The research spanned six months from January to June 2024. The experiment was conducted using 10 treatments viz., T₁-GA₃ @ 20 ppm, T₂-GA₃ @ 40 ppm, T₃-GA₃ @ 60 ppm, T₄-ZnSO₄ @ 0.4%, T₅-ZnSO₄ @ 0.6%, T₆-ZnSO₄ @ 0.8%, T₇-Borax @ 0.2%, T₈-Borax @ 0.4%, T₉-Borax @ 0.6% and T₁₀-Control (Water spray), which were replicated thrice in Randomized Block Design. The findings of the experiment clearly show that the foliar spray of 0.4% borax significantly influenced fruit set (62.05%), fruit drop (40.98%), fruit retention (59.02%), fruit cracking (5.90%), length of fruit (3.98cm), diameter of fruit (2.80cm), fruit weight (12.18g), pulp weight (8.04g), fresh seed weight (2.09g), peel weight (1.79g), pulp: stone ratio (3.97), total soluble solid (19.45%), total sugar (18.32%) and titratable acidity (0.43%) contents in the north Indian plains.

Key Words: Litchi, Zinc sulphate, borax, GA₃, Fruit drop, Cracking, Quality attributes

Introduction

The litchi (*Litchi chinensis* Sonn.) is a member of the Sapindaceae family and an important subtropical evergreen fruit tree originating in South China. It is valued for its pearly white, translucent, juicy, and succulent aril or edible pulp, which contains various nutrients such as vitamins, proteins, organic acids, pigments, and carbohydrates. However, litchi cultivation is limited to a few regions due to its specific climate requirements, and the crop faces challenges like irregular blooming, poor fruit set, excessive fruit drop, low yield, cracked fruit, and poor quality.

Litchi is a prolific producer, but few blooms turn into fruit due to poor pollination and early flower and fruit loss, resulting in poor fruit set. Despite the abundance of other fresh fruits in the market during May and June, litchi remains in

high demand due to its distinct flavour, colour and taste (Hossain *et al.* 2014).

Fruit cracking is a significant issue affecting various fruits, including litchi, citrus, grapes, date palm, pomegranate and cherry. Factors like varietal differences and extreme environmental conditions, such as intense irrigation after dry spells and sudden temperature fluctuations, contribute to fruit cracking in litchi during the hot summer. This can lead to substantial losses, up to 50% or more (Mandal and Mitra, 2014). Cracks diminish the affected fruits' marketing value and processing quality while also providing entry points for insects and fungi. (Kanwar and Nijjar, 1975).

Plant growth regulators play a crucial role in various physiological processes in various crops. GA₃ enhances fruit size, promotes flowering and fruiting, and increases overall growth.

Micronutrients like zinc and boron are also essential for proper plant development, fruit quality, and yield. Zinc serves as a metal activator for enzymes, while boron deficiency leads to sterile, malformed flowers. The Dehradun variety of litchi is prone to cracking and sun-burn but produces a medium to high yield (Menzel and Simpson, 1987).

Methods and Materials

The study was conducted in the Horticulture Garden, Department of Fruit Science, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur. The work was carried out from January to June 2024. The Kanpur region is characterized by an extreme temperature regime, with severe winters, hot summers, and a semi-arid subtropical climate. The area experiences average annual rainfall ranging from 800 to 850 millimeters, with the majority of precipitation occurring during the June to September monsoon season, while the remaining months see 60 to 100 millimeters of rainfall on average. The winter season in Kanpur is marked by average maximum and minimum temperatures of 22°C and 8°C respectively, in January, while the summer months from April through June it is reported between 35°C and 48°C. The experiment was conducted using 10 treatments *viz.*, T₁-GA₃ @ 20 ppm, T₂-GA₃ @ 40 ppm, T₃-GA₃ @ 60 ppm, T₄-ZnSO₄ @ 0.4%, T₅- ZnSO₄ @ 0.6%, T₆- ZnSO₄ @ 0.8%, T₇-Borax @ 0.2%, T₈-Borax @ 0.4%, T₉-Borax @ 0.6% and T₁₀-Control (Water spray), which were replicated thrice in Randomized Block Design. The GA₃ solution was prepared by dissolving 20 mg GA₃ in a small amount of alcohol and diluting it to 1000 ml with distilled water. Additionally, 40 ppm and 60 ppm GA₃ solutions were prepared using the same method. Aqueous zinc sulfate solutions were prepared by dissolving varying amounts of the compound in 10 liters of distilled water. Specifically, a 40g/10L solution and two additional solutions containing 60g/10L and 80g/10L of ZnSO₄ were prepared. Similarly, borax solutions were prepared by dissolving 20 mg/10L, 40g/10L, and 60g/10L of the compound in 10 liters of distilled water. Comprehensive observations were collected from each experimental treatment across all three replications of the study to assess the

effects of the treatments thoroughly. *viz.*, Fruit set (%), fruit drop (%), fruit retention (%), fruit cracking (%), length of fruit (cm), diameter of fruit (cm), fruit weight (g), pulp weight (g), fresh seed weight (g), peel weight (g), pulp: stone ratio, total soluble solid (%) and total sugar (%) content after harvest were studied as per method suggested in (AOAC (1990)). The experimental data were analysed statistically with analysis of variance method given by Panse and Sukhatme (1985).

Results and Discussion

Fruit set, fruit drop and retention

The present study investigated the influence of Gibberellic acid, Zinc sulphate, and Borax on various fruiting parameters of litchi. The results clearly demonstrated that the application of these treatments had a significant impact on the number of fruits set (Table 1), fruit drop, and fruit retention per plant (Fig 1 & 2). Notably, the maximum fruit set (62.05%) with minimum fruit drop (40.98%), and maximum fruit retention (59.02%) were observed in plants treated with borax at a concentration of 0.4%. This was closely followed by the treatment with GA₃ at 60 ppm exhibited (61.65, 50.89 and 49.11%, respectively), while, the control plants exhibited the minimum fruit set (50.46%), maximum fruit drop (69.89%), and minimum fruit retention (30.11%). This increase in fruit retention and reduction in fruit drop per cent might be due to an increase in the endogenous level of auxin and other metabolites. The role of zinc is also known to be essential for the biosynthesis of auxin (IAA), as it is an activator of the enzyme tryptophan synthesis. These results are in accordance with Kumar *et al.* (2008) and Vashistha *et al.* (2010) in mango cv. Amrapali. Applying borax and zinc sulphate in moderate concentrations may assist in maintaining the plants' improved nutritional condition, which could consequently enhance fruit retention and mitigate early fruit drop. These results are consistent with the outcome of Dixit *et al.* (2013), Chauhan *et al.* (2019) and Das *et al.* (2020), Gupta *et al.* (2022) in litchi.

Fruit Cracking (%)

The application of GA₃ and micronutrients substantially diminished fruit cracking compared

to the control treatment. The lowest (5.90%) degree of fruit cracking was noted in plants treated with 0.4% borax, followed by the 0.6% borax treatment, which exhibited 5.95% fruit cracking. Conversely, the untreated (control) plants displayed the highest (23.25%) level of fruit cracking (Table 1). Spraying of borax was observed to be more effective than GA₃ and ZnSO₄ applications. It is well established that borax and zinc sprays can regulate auxin levels in plants. This may have stimulated the synthesis of tryptophan and indirectly modulated water relations within the plants. The application of auxin may have increased the osmotic pressure of the cellular sap, thereby induced water uptake and reduced the incidence of fruit cracking. The findings follow the reports of **Kaur (2017)**, **Chauhan *et al.* (2019)** and **Gupta *et al.* (2022)** in litchi.

Fruit length, diameter, fruit weight and pulp weight

Foliar application of the plant growth regulator gibberellic acid and the micronutrients, such as zinc sulphate and borax, significantly improved the physical characteristics of the fruits compared to the control (Table 1 & 2). Conversely, decreasing the concentration of these micronutrients and the plant growth regulator resulted in diminished fruit length, diameter, weight, and pulp weight. This is because micronutrients and GA₃ are essential for the translocation of food materials from their source to the storage organs. According to the data presented in the table, the foliar application of borax @ 0.4% resulted in the highest recorded values of fruit length (3.98cm), diameter (2.80cm), weight (12.18g), and pulp weight (8.04g), closely followed by the application of GA₃ @ 60 ppm noted (3.78cm, 2.77cm, 12.05g & 7.96g, respectively), whereas, minimum fruit length (3.32cm), diameter (2.56cm), fruit weight (10.28g) and pulp weight (5.70g) was recorded under control. The increase in fruit length, diameter, weight, and pulp weight in litchi fruit may be attributed to the influence of mineral nutrients, particularly boron, which appears to play a direct role in accelerating cell division and elongation processes, thereby enhancing fruit size and weight. The augmented fruit weight could be attributed to the rapid

expansion of individual cells or the fact that foliar application of boron facilitated this increase by maintaining lower levels of auxins in various parts of the fruit, which in turn promoted fruit growth. These results are consistent with the outcome of **Haq *et al.* (2013)**, **Gupta *et al.* (2022)**, **Kaur (2017)** in litchi.

Fresh seed weight, peel weight and pulp: seed ratio

The foliar application of a plant bioregulator and micronutrients led to a significant decrease in fresh seed and peel weights while maximizing the pulp-to-stone ratio (Table 2). This indicates that the treatment had a positive effect on the overall quality attributes of litchi fruits. Significantly, minimum seed weight (2.09g), peel weight (1.79g) and maximum pulp: stone ratio (3.97) were noted when the plants were treated with 0.4% borax. It was closely followed by the treatment of GA₃ @ 60 ppm, which exhibited (2.27g, 1.82g and 3.50, respectively); whereas maximum seed weight (2.79g), peel weight (2.05g) and minimum pulp: stone ratio (1.94) was recorded under control. Boron treatment resulted in fruits with smaller stone size. This may be attributed to boron's involvement in indole-3-acetic acid metabolism, which can reduce stone size and peel weight. The decrease in stone and peel weight may be due to auxins inducing parthenocarpic to some degree, leading to lower stone weight. The application of boron appears to have enhanced pulp weight and reduced stone weight, consequently increasing the pulp-to-stone ratio as reported by **Singh *et al.* (2017)** in mango, **Saraswat *et al.* (2006)** and **Kaur (2017)** in litchi.

Total Soluble Solids and total sugars

The data presented in the table given below revealed that the fruits produced from the plants treated with borax at a concentration of 0.4% had the maximum (19.45%) total soluble solids and total sugars (18.32%) contents, followed by the fruits from the plants treated with GA₃ at a concentration of 60ppm which exhibited 19.36% TSS and 18.22% total sugar whereas lowest TSS (17.60%) and total sugar (16.37%) was obtained under control (Table 2). The application of borax may have stimulated the mobilization of nutrients, leading to an enhanced accumulation of

carbohydrates and improved fruit quality attributes. Additionally, boron's role in facilitating trans-membrane sugar transport may have contributed to the increase in total soluble solids and total sugars observed in boron-treated trees. These findings align with the results reported by **Kaur (2017)** in litchi, **Singh et al. (2017)** in mango, and **Chaturvedi et al. (2005)** in strawberry.

Titrateable acidity

The foliar application of gibberellic acid and micronutrients such as zinc and borax were found to decrease the titrateable acidity content in fresh litchi fruits. The lowest percentage (0.43%) of titrateable acidity was recorded in fruits harvested from plants treated with Borax at 0.4%, followed by GA₃ at 60 ppm, which noted 0.44% titrateable acidity (Table 2). In contrast, the highest (0.53%) titrateable acidity was observed in the fruits harvested from the control plants, which did not receive any foliar applications of GA₃ or micronutrients. The application of borax may have accelerated fruit maturation, resulting in a decrease in acidity. This could be attributed to the breakdown of acids and the enhanced conversion of acids into sugars and their derivatives through the reversal of the glycolytic pathway or their consumption during respiration. This is consistent with the findings of previous studies on litchi by **Kaur (2017)**, **Singh et al. (2018)** in litchi and **Singh et al. (2017)** in mango.

Table 1. Effect of foliar feeding of Gibberellic acid and micronutrients (Zinc sulphate and Borax) on fruit set, cracking and physical parameters of litchi cv. Dehradun

Treatment	Fruit set (%)	Fruit Cracking (%)	Length of fruit (cm)	Diameter of fruit (cm)	Fruit Weight (g)
T1-GA3 @ 20ppm	58.04	13.53	3.66	2.68	11.23
T2-GA3 @ 40ppm	60.14	12.85	3.76	2.75	11.91
T3-GA3 @ 60ppm	61.65	10.12	3.78	2.77	12.05
T4-ZnSO4 @ 0.4%	51.25	13.27	3.58	2.63	10.49
T5-ZnSO4 @ 0.6%	54.15	13.34	3.62	2.65	10.84
T6-ZnSO4 @ 0.8%	56.25	13.95	3.65	2.67	11.02
T7-Borax @ 0.2%	53.04	8.00	3.60	2.64	10.60
T8-Borax @ 0.4%	62.05	5.90	3.98	2.80	12.18
T9-Borax @ 0.6%	58.65	5.95	3.68	2.72	11.36
T10-Control	50.46	23.25	3.32	2.56	10.28
SE. (m)±	0.909	0.265	0.056	0.034	0.211
CD at 5% level	2.783	0.793	0.169	0.102	0.633

Table 2. Effect of foliar feeding of Gibberellic acid and micronutrients (Zinc sulphate and Borax) on Quality parameters of litchi cv. Dehradun

Treatment	Pulp Weight (g)	Fresh Seed Weight (g)	Peel weight (g)	Pulp: stone ratio	Total soluble solid (%)	Total Sugar (%)	Titrateable acidity (%)
T1-GA3 @ 20ppm	6.85	2.46	1.91	2.78	18.98	17.80	0.48
T2-GA3 @ 40ppm	7.63	2.31	1.86	3.35	19.25	18.09	0.46
T3-GA3 @ 60ppm	7.78	2.27	1.82	3.50	19.36	18.22	0.44
T4-ZnSO4 @ 0.4%	6.07	2.60	2.00	2.26	18.02	16.80	0.52
T5-ZnSO4 @ 0.6%	6.43	2.53	1.95	2.51	18.43	17.23	0.50
T6-ZnSO4 @ 0.8%	6.61	2.50	1.92	2.64	18.45	17.26	0.49
T7-Borax @ 0.2%	6.16	2.58	1.97	2.34	18.20	16.99	0.51
T8-Borax @ 0.4%	8.04	2.09	1.79	3.97	19.45	18.32	0.43
T9-Borax @ 0.6%	6.99	2.42	1.88	2.91	19.10	17.93	0.47
T10-Control	5.70	2.79	2.05	1.94	17.60	16.37	0.53
SE. (m)±	0.081	0.022	0.025	0.042	0.280	0.927	0.008
CD at 5% level	0.242	0.065	0.075	0.125	0.839	0.310	0.025

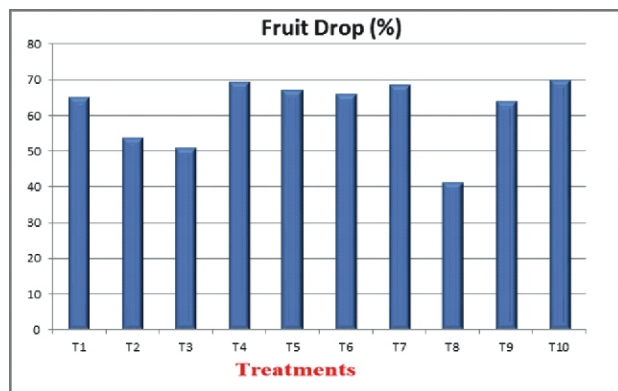


Fig. 1: Effect of Gibberellic acid Zinc sulphate and Borax on fruit drop in litchi

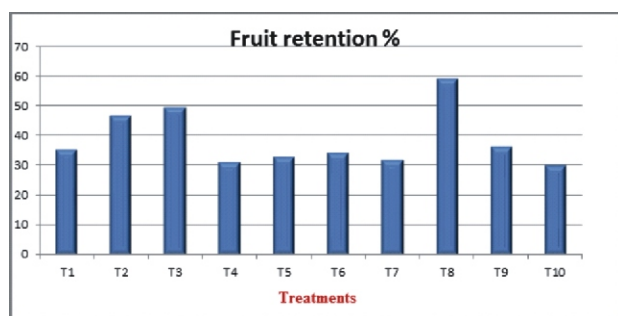


Fig. 2: Effect of Gibberellic acid, zinc sulphate and boron on fruit retention (%) in litchi

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EFFECT OF INTEGRATED NUTRIENT MANAGEMENT ON QUALITY TRAITS, SOIL NUTRIENT AVAILABILITY (NPK) AND ECONOMIC RETURNS IN RADISH (*RAPHANUS SATIVUS* L.)

Aditya Narayan Dadheech¹, M. K. Poonia²,
S.K. Moond³, Prem Lal Gadri⁴, Ronak Kuri⁵

M.Sc. Researcher^{1*,4} Department of Horticulture, CoA, Jodhpur

²Professor Department of Horticulture, CoA, Sumerpur, Pali (Life member of society)

³Professor Department of Horticulture, CoA, Jodhpur

⁵Ph.D. Scholar Department of Horticulture, CoA, Jodhpur

Agriculture University, Jodhpur (Rajasthan)-342 304

*Corresponding Author Email-maheshkpoonia@gmail.com

Abstract

A field experiment was conducted at the Instructional Farm, College of Agriculture, Jodhpur, during the *Rabi* season of 2023-24 to assess the impact of integrated nutrient management on growth and yield of radish (*Raphanus sativus* L.). The study comprised fourteen treatments arranged in a Randomized Block Design (RBD) with three replications. The findings revealed that the application of 100% RDF + 4.0 t Vermicompost + Microbial Consortia @ 12.5 kg/ha resulted in the maximum total soluble solids (5.07 °B), ascorbic acid content (14.08 mg/100 g), chlorophyll content of leaves (0.789 mg/100 g) and highest available nitrogen (186.77 kg/ha), available phosphorus (24.80 kg/ha), available potassium (337.77 kg/ha) compared to the control.

Key Words: Recommended dose of fertilizers (RDF), Vermicompost, Microbial Consortia

Introduction

Radish (*Raphanus sativus* L.) is a popular root vegetable, locally known as *mooli*. It belongs to the genus *Raphanus*, family *Brassicaceae* and originated from Central and Western China as well as India (Dongarwar *et al.*, 2017). Due to its medicinal properties, it is prescribed for patients suffering from piles, chronic diarrhea, liver troubles and jaundice (Shrivastava *et al.*, 2022). The roots are said to be useful in urinary complaints, gastrodynia, enlarged spleen, and stomach troubles. The juice of fresh leaves is used as a diuretic and laxative. The leaves of radish are a good source for the extraction of protein on a commercial scale (Kumar *et al.*, 2014). The chemical composition of per 100 g radish is as follows; energy-16 kcal, carbohydrates- 3.4 g, sugar- 1.86 g, dietary fiber-1.6 g, fat- 0.1 g, protein-

0.68 g, thiamine- 0.012 mg, riboflavin- 0.039 mg, niacin- 0.254 mg, pantothenic acid- 0.165 mg, vitamin B₆- 0.071 mg, folate- 25 ig, vitamin C- 14.8 mg, calcium- 25 mg, iron- 0.34 mg, magnesium- 10 mg, manganese- 0.069 mg, phosphorus- 20 mg, potassium- 233 mg and zinc- 0.28 mg (Tripathi *et al.*, 2017). INM are to ensure the efficient and judicious use of all the major sources of plant nutrients in an integrated manner, so as to obtain maximum economic yield without diminishing soil fertility in order to sustain agricultural productivity and farm profitability (El-Ramady *et al.*, 2014). The use of organic fertilizer, compost, vermicompost and low dose chemical fertilizer improves radish production (Subramani *et al.*, 2010). In microbial consortia, the organisms work together in a complex and synergistic way, where all benefit from the activities of others in the community

(Nandish *et al.*, 2021). The vermicompost has the positive impact on plant growth (Lazcano and Dominguez, 2011; Gholami *et al.*, 2018). They accelerate the process of crop ripening along with the improvement of several qualitative parameters of the grown crops (Gutierrez-Miceli *et al.*, 2007; Singh *et al.*, 2008; Sinha *et al.*, 2011).

Material and methods

The experiment was conducted during *Rabi* 2023-24 at Instructional Farm, College of Agriculture, Jodhpur; situated at an altitude of 231 m above mean sea level between 26°15" to 26°45" North latitude and 73°00" to 73°29" East longitude. The region falls under agro-climatic zone Ia (Arid Western Plains Zone) of Rajasthan. The climate of Jodhpur is usually arid, with dry, warm, and sunny winters and average annual precipitation is about 367 mm. The average daily maximum and minimum temperature fluctuated between 36.5 °C and 7.6 °C, respectively, with mean daily relative humidity ranged between 98.00 and 29.00 percent. The soil of experimental field was sandy-loam in texture, low in organic carbon (0.13%) and available nitrogen (174.2 kg/ha), medium in phosphorus (21.9 kg/ha) and high in potassium (323.4 kg/ha).

The treatments consisted of fourteen treatment combinations, including Control [RDF (100 Kg N, 60 Kg P₂O₅ and 100 Kg K₂O/ha)] (T₁), RDF + Microbial Consortia @ 12.5 kg/ha (T₂), 100% RDF + 2.0 t Vermicompost (T₃), 75% RDF + 2.0 t Vermicompost (T₄), 50% RDF + 2.0 t Vermicompost (T₅), 100%RDF + 4.0 t Vermicompost (T₆), 75%RDF + 4.0 t Vermicompost (T₇), 50% RDF + 4.0 t Vermicompost (T₈), 100%RDF + 2.0 t Vermicompost + Microbial Consortia @ 12.5 kg/ha (T₉), 75%RDF + 2.0 t Vermicompost + Microbial Consortia @ 12.5 kg/ha (T₁₀), 50% RDF + 2.0 t Vermicompost + Microbial Consortia @ 12.5 kg/ha (T₁₁), 100%RDF + 4.0 t Vermicompost + Microbial Consortia @ 12.5 kg/ha (T₁₂), 75%RDF + 4.0 t Vermicompost + Microbial Consortia @ 12.5 kg/ha (T₁₃) and 50% RDF + 4.0 t Vermicompost + Microbial Consortia @ 12.5 kg/ha (T₁₄) were tested in Randomized Block Design (RBD) with three replication. Data were recorded on quality parameters namely TSS (°Brix), ascorbic acid content (mg/100 g), chlorophyll

content of leaves (mg/100 g) and soil parameter including available nitrogen in soil (kg/ha), available phosphorus in soil (kg/ha), available potassium in soil (kg/ha) and economics.

Result and discussion

Quality parameters

A perusal of data revealed that the application of plant nutrients through integrated nutrient management significantly affected the quality and soil attributes of radish. It is evident from the data that the application of 100% RDF + 4.0 t Vermicompost + Microbial Consortia @ 12.5 kg/ha (T₁₂) resulted maximum total soluble solids (5.07 °B), followed by (5.01 °B), with the application of 75% RDF + 4.0 t Vermicompost + Microbial Consortia @ 12.5 kg/ha (T₁₃). The increase in total soluble solids may be attributed to the increased nitrogen through fertilizers, which apparently helped in vigorous vegetative growth and favoured photosynthetic activity for greater accumulation of food material *i.e.* carbohydrates that increased TSS content in plants (Yadav *et al.* 2022).

The maximum value of ascorbic acid content (14.08 mg/100 g) and chlorophyll content of leaves (0.789 mg/100 g) was observed under the application of 100% RDF + 4.0 t Vermicompost + Microbial Consortia @ 12.5 kg/ha (T₁₂) followed by ascorbic acid content (14.02 mg/100 g), chlorophyll content of leaves (0.777 mg/100 g), with the application of 75% RDF + 4.0 t Vermicompost + Microbial Consortia @ 12.5 kg/ha (T₁₃). According to Sawant *et al.* (2023) maximum ascorbic acid recorded might be due to optimum doses of nutrients resulting in increased plant height, number of leaves, root length and root diameter. Thus, resulting in more scope for photosynthates and translocating to the storage organs, ultimately increasing the storage of more carbohydrates. This ultimately is reflected in TSS and hormonal metabolism of plant system which has direct influence for Vitamin-‘C’ content in root. Chlorophyll content was found due to increased availability of macro and micro nutrients which would retard leaf senescence and improve the photosynthates assimilation. The results were in close conformity with Shanu *et al.* (2019) in carrot, Kumar *et al.* (2021), Balbande *et al.* (2023), Kaur *et al.* (2023), Sawant *et al.* (2023) in radish, Nath *et*

al. (2023) in lettuce and Kondal *et al.* (2024) in beetroot.

Soil parameters

From the results of the present investigation, it clearly shows that the highest amount of available nitrogen (186.77 kg/ha), phosphorus (24.80 kg/ha) and potassium (337.77 kg/ha) in the soil after harvest was obtained in the treatment T₁₂ (100% RDF + 4.0 t Vermicompost + Microbial Consortia @ 12.5 kg/ha) over control. However, initial available nitrogen (174.2 kg/ha), phosphorus (21.9 kg/ha) and potassium (323.4 kg/ha) were present in soil before planting. Significant build up of available N, P₂O₅ and K₂O status could be due to organic matter added with the addition of vermicompost, which remains longer period in the soil as residual nutrients and the presense of organic matter there might be more activity of microbes in soil. The results were in close conformity with Mohammadi *et al.* (2017), Mali (2018), Sampathi (2022) and Teja (2021) in radish.

Economics

Higher money value and less cultivation cost are the desirable traits for getting higher returns. The following treatments, the maximum cost of cultivation (?/ha 71700.00), gross returns (?/ha 291223.70) and net returns (?/ha 219523.70) were recorded in T₁₂ (100% RDF + 4.0 t Vermicompost + Microbial Consortia @ 12.5 kg/ha) and maximum B:C ratio (1: 3.10) was recorded in 75% RDF + 4.0 t Vermicompost + Microbial Consortia @ 12.5 kg/ha (T₁₃). Whereas the minimum gross return and net return was recorded in (T₁) control [RDF (100 Kg N, 60 Kg P₂O₅ and 100 Kg K₂O/ha)]. Similar findings was observed by Verma *et al.* (2017) and Khede *et al.* (2019). Economically the study suggested that the combined application of inorganic and organic manure and fertilizers (75% RDF + 4.0 t Vermicompost + Microbial Consortia @ 12.5 kg/ha) were highly beneficial for all the parameters of radish.

Table: 1 Effect of integrated nutrient management on quality of radish

S.N.	TSS (oBrix)	Ascorbic acid content (mg/100 g)	Chlorophyll content of leaves (mg/100 g)
T1	4.41	12.58	0.684
T2	4.51	12.84	0.698
T3	4.75	13.41	0.735

T4	4.69	13.33	0.728
T5	4.44	12.69	0.687
T6	4.83	13.49	0.750
T7	4.79	13.44	0.744
T8	4.48	12.76	0.693
T9	4.91	13.58	0.764
T10	4.88	13.54	0.758
T11	4.55	12.88	0.704
T12	5.07	14.08	0.789
T13	5.01	14.02	0.777
T14	4.58	12.91	0.710
SEm±	0.05	0.17	0.008
CD (P =0.05)	0.15	0.48	0.023

Table 2: Effect of integrated nutrient management on available soil parameters of radish

S. N.	N (kg/ha)	P ₂ O ₅ (kg/ha)	K ₂ O (kg/ha)
T1	177.33	22.76	326.75
T2	179.59	22.98	329.17
T3	183.39	23.73	333.32
T4	182.42	23.50	332.79
T5	180.95	23.11	329.64
T6	184.68	24.20	334.87
T7	183.66	23.97	333.70
T8	181.73	23.24	331.07
T9	185.43	24.50	336.11
T10	184.97	24.32	335.19
T11	182.27	23.32	332.45
T12	186.77	24.80	337.77
T13	185.98	24.62	336.83
T14	183.58	23.85	333.53
Initial value	174.2	21.9	323.4
SEm±	6.45	0.36	0.11
CD (P =0.05)	18.74	1.03	0.32

Table 3: Effect of integrated nutrient management on economics of radish

S.N.	Total cost	*Gross returns (?/ha)	Net returns (?/ha)	B: C Ratio
T1	79925.00	210477.00	130552.00	1.63
T2	81700.00	216690.33	134990.33	1.65
T3	59925.00	227919.69	167994.69	2.80
T4	58098.24	221498.35	163400.11	2.81
T5	56272.14	209690.34	153418.20	2.73
T6	69925.00	266770.36	196845.36	2.82
T7	68098.24	261490.36	193392.12	2.84
T8	66272.14	227290.34	161018.20	2.43
T9	61700.00	246954.36	185254.36	3.00
T10	59873.24	242343.70	182470.46	3.05
T11	58047.14	219325.01	161277.87	2.78
T12	71700.00	291223.70	219523.70	3.06
T13	69873.24	286397.03	216523.79	3.10
T14	68047.14	227018.35	158971.21	2.34

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“STUDY THE RESPONSES OF INJECTION METHOD OF NPK FERTILIZATION ON QUALITY OF DATE PALM CV. HALAWY”

Jitendra Gurjar, R.S. Rathore, P.K. Yadav, , R.K. Meena, A.K. Sharma,
S.K. Kharia, and B.D.S. Natawat

College of Agriculture, Bikaner, SKRAU, Bikaner, Rajasthan

*Corresponding Author Email-@gmail.com

Abstract

The present study entitled “*Study the responses of injection method of NPK fertilization on quality of Date Palm (Phoenix dactylifera L.) cv. Halawy*” was conducted from November 2022 to July 2024 at the Date Palm Research Centre, Swami Keshwanand Rajasthan Agricultural University, Bikaner, located in a hot arid agro-ecological zone with sandy, low-retention soils. The experiment aimed to evaluate the effects of different levels of NPK fertilizer (0%, 25%, 50%, and 75% of the basal dose) applied through trunk and soil injection methods on the biochemical parameters of date palm fruits.

The findings revealed that both trunk and soil injection methods significantly improved fruit quality traits including total soluble solids (TSS), total sugars, and reducing sugars, while reducing acidity. The highest quality improvements were recorded under the 75% NPK level (T3 and S3), with soil injection (S3) marginally outperforming trunk injection (T3) in enhancing TSS (36.88%), total sugars (36.61%), and reducing sugars (32.11%). Acidity levels were lowest in S3 (0.261%), supporting a better sugar-to-acid ratio, an important indicator of fruit palatability. Phenol and soluble tannin contents showed a slight but non-significant decrease across increasing NPK levels. These results underscore the potential of NPK injection fertilization—particularly through soil application—as a sustainable, efficient strategy to boost the quality of date palm fruits under arid conditions, offering a promising alternative to traditional fertilization practices.

Key Words: Date palm (*Phoenix dactylifera* L.), NPK fertilization, trunk injection, soil injection, fruit quality, total soluble solids (TSS), sugars, acidity, arid region horticulture, Halawy cultivar, nutrient management.

Introduction

Date palm (*Phoenix dactylifera* L.) is considered as an important crop in arid regions of the world (Al-Shahib and Marshall 2003; Aseeri et al., 2021). It is not only grow in the most hard desert conditions, but tolerate an excess amount of alkalinity in the soil that will kill any other crop (Shareef et al., 2021a). It is one of the fruit crops that can grow in adverse conditions due to its capability to tolerate drought and stress (Huntrods 2011; Shareef and Al-Khayri, 2021). Along with the olive and the fig, the three represent an ancient group of fruit trees closely

associated with the commencements of agriculture and the sustenance of humankind in the arid regions of the old World (Al-Khayri et al., 2013).

Globally date palm covers an area of 1.11 million ha. with production of 9648.17 MT and productivity 7.65 ton/ha FAO, 2023. Egypt is one of the maximum date palm producing country in the World. The Egypt, Saudi Arabia, Iran, Algeria, Iraq, Pakistan and Sudan are the top date producing countries in the world. In India date palm are cultivated in the state of Gujarat, Rajasthan, Tamil Nadu and Punjab. India spends US\$ 230 Million/year for import of dates and its product known for their high nutritional value.

Date fruit provide abundant quantities of iron, potassium, calcium, nicotinic acid and small amount of protein, copper, magnesium, chlorine, sulphur and vitamin A, B1 and B2 (Al-Qarawi et al., 2004; Barghini et al., 2007; Chao and Krueger, 2007; Al-Harrasi et al., 2014; Siddiq et al., 2013; Eoin, 2016).

Date palm contain sugar (60-65%), fiber (2-6%), protein (1-3%), less than 0.52-3.25% fat, mineral matter and pectic substance (Shafiei et al., 2010 ; Al-Shwyeh, 2019 ; Al-Mssallem et al., 2020). Its fresh fruit can supplement the dietary need of the desert people and provide about 3000 calories per kg. Dates are valued for their high quality due to a favorable sugar-to-acid ratio, low moisture content, and good skin integrity, making them a naturally preserved, energy-rich dessert with minimal acidity. They contain 70-80% carbohydrates (primarily fructose and glucose) and are a rich source of essential minerals like calcium, iron, magnesium, phosphorus, potassium, zinc, selenium, and manganese, boosting their nutritional value (Al-Farsi et al., 2005; Elleuch et al., 2008; Chao and Krueger, 2007; Al-Harrasi et al., 2014; Siddiq et al., 2013; Eoin, 2016). Aqueous extracts of date have a potential antioxidant and anti-mutagenic activity (Biglari et al., 2008; Saafi et al., 2009).

NPK fertilizers can be applied through various methods, including broadcasting, banding, fertigation, and trunk injection. Each method has its advantages and limitations, with considerations for application timing, nutrient availability, and environmental impacts. Fertigation, for example, allows for precise nutrient delivery through irrigation systems, while trunk injection offers targeted nutrient delivery directly to the plant's vascular system (Ferreira et al., 2023).

Trunk injection is an innovative method of nutrient delivery that has gained attention in recent years, particularly in the field of horticulture and arboriculture. This technique involves the direct injection of liquid fertilizers, pesticides, or other nutrient solutions into the vascular system of trees through the trunk, bypassing the traditional soil-root interface. By utilizing this approach, growers can enhance nutrient absorption, improve plant health, and

reduce the environmental impacts commonly associated with conventional fertilization practices (Drwesh, 2015; Jubeir and Ahmed, 2019a). Injection nutrient solution save 90-95% of nutrients and keep a clean environment (Mahmud, 2009; Luaces et al., 2020; Archer et al., 2022).

Materials and methods

The present investigation entitled, "Study the responses of injection method of NPK fertilization on growth, yield and quality of Date palm (*Phoenix dactylifera* L.) cv. Halawy" was conducted at Date Palm Research Centre and Department of Horticulture, College of Agriculture, Swami Keshwanand Rajasthan Agriculture University, Bikaner during November 2022 to July 2024.

Geographically, the centre is situated 7 km from Bikaner on NH-15, at an altitude of 234.7 meters above mean sea level, with coordinates of latitude 28° 01'N and longitude 73° 22'E. According to the Agro-Ecological Region map by the National Bureau of Soil Survey and Land Use Planning (NBSS and LUP), Bikaner falls within Agro-Ecological Region No. 2 (M 9 E 1) of the arid ecosystem, characterized by hot, arid conditions with desert and saline soils. The area features deep, sandy and coarse loamy desert soils with low water retention capacity and receives less than 300 mm of precipitation annually. The Potential Evapotranspiration (PET) in this region ranges from 1500 to 2000 mm, as reported by the National Agriculture Research Project (NARP).

Bikaner is classified in Agro-Climate Zone (IC), a designation derived from the original Agro-Climate Zone (IA). This zone is recognized as the hyper-arid, partially irrigated north-western plain zone (IC). Additionally, according to the National Planning Commission, Bikaner is situated in Agro-Climate Zone XII, which corresponds to the Western Dry Region of India.

Experimental Details

Table1. Details of the treatments

Table 10.2 Details of the treatments

Treatment	Treatment content
NPK trunk injection (Factor A)	
T0 0%	Control (Water trunk injection)
T1 25%	25% of NPK/tree through trunk injection (25% of basal doses)

T2 50%	50% of NPK/tree through trunk injection (25% of basal doses)
T3 75%	75% of NPK/tree through trunk injection (25% of basal doses)
NPK soil injection (Factor B)	
S0 0%	Control (Water soil injection)
S1 25%	25% of NPK/tree through soil injection (100% basal doses)
S2 50%	50% of NPK/tree through soil injection (100% basal doses)
S3 75%	75% of NPK/tree through soil injection (100% basal doses)

Note: For trunk injection, each level is based on 25% of the basal dose (500:250:250 g/tree). In contrast, for soil injection, each level is based on 100% of the basal dose (500:250:250 g/tree).

3.6 Application of Treatments

The treatments were administered from November to April, focusing on the precise injection of NPK solutions into the trunk and soil. In trunk injection, the total fertilizer dose was divided into six equal installments, with each application carefully injecting 25% of the basal NPK dose of 500:250:250 g/tree. The treatment combinations were structured to provide a total of 25% of the fertilizer doses at 0%, 25%, 50% and 75%. In soil injection, the total fertilizer dose was split into six equal installments, applying 0%, 25%, 50%, and 75% of the total NPK dose of 500:250:250 g/tree.

The sources of fertilizer included water-soluble NPK 19:19:19 and urea. The NPK doses were adjusted according to the treatment combinations, with 50% of the nitrogen supplied from the water-soluble NPK 19:19:19 and 100% of the phosphorus and potassium also sourced from this fertilizer. The remaining 50% of nitrogen was provided through urea.

The treatment solutions were applied using a 200 ml syringe, ensuring precise and effective delivery of nutrients into the trunk and soil. This method optimized nutrient availability and supported the plants' growth throughout the growing season.

Trunk injection procedure:

Three holes were drilled on both sides of the trunk, following the appropriate depth and diameter based on the trunk's height and girth (e.g., for a 1-meter trunk height, holes were drilled

to a depth of 10-12 cm with a diameter of 12 mm). The NPK solution was injected into each hole using the 200 ml syringe and the holes were sealed with silicone paste to prevent leakage and contamination. After each injection, a spray of Copper Oxychloride (COC) was applied to control fungal infections.

Soil injection procedure:

Four holes were dug around each plant at a distance of 3 feet from the trunk. The holes were 2.5 feet deep and had a diameter of 6 inches. PVC pipes, each 1 meter in length, were inserted into the holes to facilitate the direct application of the NPK and urea solutions into the soil. This method ensured an even distribution of nutrients and minimized losses.

This method ensured that the NPK solution was precisely delivered to the trunk and root zones, optimizing nutrient uptake and minimizing potential environmental impact.

Observation recorded

The biochemical analysis of the fruit included measurements of Total Soluble Solids (TSS), acidity, phenolic content, soluble tannins, total sugars, reducing sugars, and non-reducing sugars. TSS was measured using a digital refractometer and expressed in °Brix after correction to 20°C. Acidity was determined by titrating pulp juice against N/10 NaOH and calculated using a standard formula. Phenolic content was estimated using ethanol extraction followed by reaction with Folin-Ciocalteau reagent, and the absorbance was read at 650 nm, with catechol as a standard. Soluble tannins were measured using the Folin-Denis reagent after alcohol extraction, and absorbance was taken at 760 nm using tannic acid as the standard. Total sugars were determined by the anthrone method after hydrolysis and neutralization, with absorbance read at 630 nm. Reducing sugars were quantified using the Nelson-Somogyi method by reacting the sample with copper reagent and measuring the absorbance at 620 nm. Non-reducing sugars were calculated by subtracting reducing sugars from total sugars and multiplying by a correction factor of 0.95.

Data were recorded in triplicate and analysed at 5% significance level using WASP 2.0 software

developed by ICAR-Central Coastal Agricultural Research Institute, Goa and expressed as mean $\pm$ standard error.

Result and discussion

4.3 Biochemical analysis of the fruits

TSS (%), Acidity (%), Phenols (mg/ g), Soluble tannins (mg/ g), Total sugars (%), Reducing sugar (%) and Non reducing sugar (%) was recorded after completion of an experiment in both the years.

5.3.1 Effect of Trunk Injection Method

The results of the study indicate that trunk injection of water-soluble NPK fertilizer significantly enhanced several biochemical quality parameters in date palm fruits (cv. Halawy). The T3 treatment (75% NPK trunk injection of the 25% basal dose) consistently produced the highest values for total soluble solids (TSS) at 36.43%, 36.64%, and 36.54% over two years and pooled data, followed closely by the T2 treatment (50% NPK trunk injection), which also exhibited significantly improved TSS values compared to the control (T0). The lowest TSS values were recorded in the T0 treatment (34.28%, 34.33%, and 34.31%).

Similarly, trunk injection significantly influenced sugar-related traits. The highest total sugars (36.16%, 36.21%, and 36.19%) and reducing sugars (31.66%, 31.71%, and 31.69%) were observed in T3, with T2 performing comparably well. In contrast, the control (T0) recorded significantly lower levels of total (33.75%) and reducing sugars (29.39%). This indicates that higher levels of trunk-injected NPK fertilizer substantially boost carbohydrate accumulation in the fruit.

Acidity levels demonstrated a notable inverse relationship with sugar content. T3 exhibited the lowest acidity values (0.264%, 0.261%, and 0.262%), significantly differing from the control (T0: 0.281%, 0.282%, and 0.281%). The improved sugar-to-acid ratio in T3 and T2 reflects enhanced fruit palatability and market quality.

While trunk injection led to a general reduction in phenol and soluble tannin content, these changes were mostly non-significant. Phenol content declined slightly from 0.579 mg/g in T0 to 0.554 mg/g in T3. Similarly, soluble tannins decreased from 3.96 mg/g in the control to 3.82

mg/g in T3. Non-reducing sugars showed minor, non-significant increases across treatments, with T3 recording a marginally higher value (4.50%) compared to T0 (4.36%).

These results align with previous studies highlighting the role of trunk injection in enhancing nutrient uptake and fruit quality in woody crops (Abdi & Hedayat, 2010; Shaaban, 2009). Nutrient mobility through direct xylem uptake ensures immediate availability, bypassing soil limitations. The observed improvements are likely due to the synergistic effects of nitrogen (boosting photosynthesis and sugar synthesis), phosphorus (enhancing nutrient transport and energy metabolism), and potassium (promoting sugar accumulation and stress resistance) (Zhang et al., 2024; Chen et al., 2022; Al-Kharusi et al., 2009). These findings support the use of trunk injection as an effective strategy for improving fruit quality, particularly under suboptimal soil or environmental conditions.

5.3.2 Effect of Soil Injection Method

The soil injection method of NPK fertilization also significantly influenced fruit quality parameters. The S3 treatment (75% NPK soil injection of the basal dose) consistently yielded the highest TSS values (36.73%, 37.04%, and 36.88%) across both years and in pooled analysis. Corresponding increases were observed in total sugars (36.54%, 36.68%, and 36.61%) and reducing sugars (32.04%, 32.19%, and 32.11%). These findings demonstrate that nutrient availability through soil injection effectively enhances sugar accumulation in date palm fruits.

In contrast, the S0 treatment (control) consistently recorded the lowest values for TSS (34.33%), total sugars (33.65%), and reducing sugars (29.27%), indicating the limitations of unfertilized conditions in promoting fruit quality. These outcomes reinforce the importance of soil-based nutrient management for improving fruit composition.

A significant reduction in fruit acidity was also observed with increasing NPK levels. The lowest acidity (0.261%) was recorded in the S3 treatment, while the highest acidity (0.283%) was found in the S0 control. This inverse relationship between sugar and acid content confirms the role of balanced NPK fertilization in improving fruit

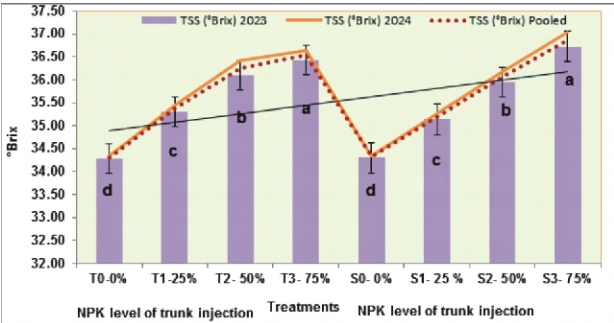
flavor and sugar-to-acid ratio—critical parameters for consumer acceptance.

The effect of soil injection on secondary metabolites such as phenols, soluble tannins, and non-reducing sugars was less pronounced. Although minor reductions in phenol (0.554 mg/g) and tannin (3.81 mg/g) content were recorded in S3, these differences were statistically non-significant when compared to the control (S0: phenols – 0.578 mg/g, tannins – 3.94 mg/g). Non-reducing sugar content remained relatively unchanged across treatments, ranging from 4.35% to 4.50%.

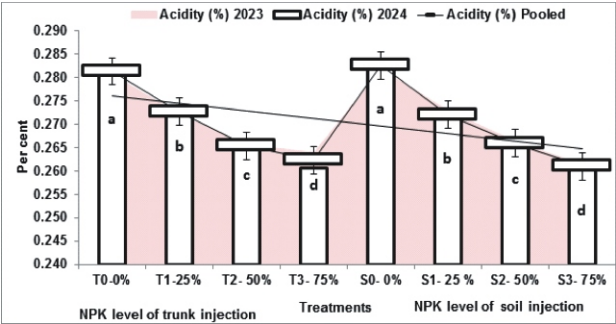
These results are consistent with earlier findings (Harhash & Abdel-Nasser, 2007;

Jahanshah et al., 2016), which emphasize the key role of potassium in carbohydrate biosynthesis, osmotic regulation, and enzyme activation. Potassium facilitates efficient translocation of assimilates, while nitrogen and phosphorus contribute to energy metabolism and nutrient transport. Soil injection ensures that these nutrients are readily available to the root system, thereby enhancing fruit quality. Furthermore, potassium’s influence on reducing acidity is well-documented, promoting a favorable sugar-to-acid balance (Shaaban, 2009; Zhang et al., 2020).

Treatment	TSS (°Brix)	Acidity (%)	Phenols (mg/g)						
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
A. NPK level of trunk injection									
T0-0%	34.28	34.33	34.31	0.281	0.282	0.281	0.577	0.582	0.579
T1-25%	35.30	35.44	35.37	0.272	0.273	0.273	0.567	0.563	0.565
b1T2- 50%	36.10	36.41	36.26	0.266	0.265	0.265	0.562	0.555	0.558
T3- 75%	36.43	36.64	36.54	0.264	0.261	0.262	0.558	0.549	0.554
S.Em.±	0.25	0.23	0.17	0.002	0.002	0.002	0.010	0.009	0.007
CD (P=0.05)	0.72	0.68	0.48	S	S	S	NS	NS	NS
B. NPK level of soil injection									
S0- 0%	34.30	34.35	34.33	0.282	0.283	0.283	0.577	0.579	0.578
S1- 25 %	35.14	35.26	35.20	0.273	0.271	0.272	0.568	0.562	0.565
S2- 50%	35.95	36.17	36.06	0.266	0.266	0.266	0.561	0.557	0.559
S3- 75%	36.73	37.04	36.88	0.261	0.261	0.261	0.558	0.550	0.554
S.Em.±	0.25	0.23	0.17	0.002	0.002	0.002	0.010	0.009	0.007
CD (P=0.05)	0.72	0.68	0.48	S	S	S	NS	NS	NS



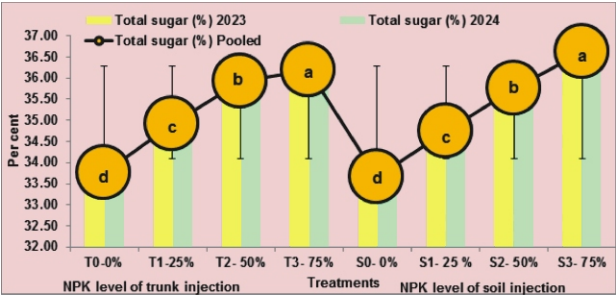
4.3.1 Individual effect of injection method of NPK fertilization on TSS of date palm cv. Halawy



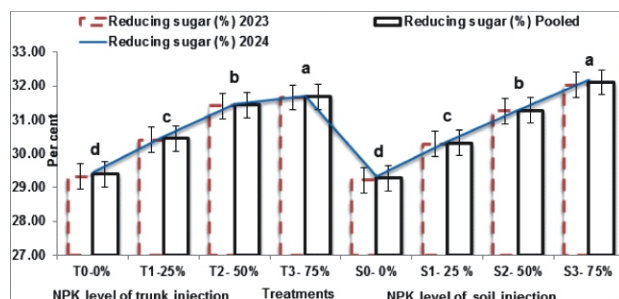
4.3.2 Individual effect of injection method of NPK fertilization on acidity of date palm cv. Halawy

Table: 4.3.2 Effect of injection method of NPK fertilization on phenols, soluble tannins, total sugars, reducing and sugar non reducing sugar of date palm cv. Halawy

Treatment	Soluble tannins (mg/ g)	Total sugars (%)	Reducing sugar (%)	Non reducing sugar (%)								
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
A. NPK level of trunk injection												
T0-0%	3.98	3.93	3.96	33.69	33.81	33.75	29.32	29.46	29.39	4.36	4.35	4.36
T1-25%	3.91	3.86	3.89	34.79	35.00	34.90	30.41	30.50	30.45	4.38	4.51	4.44
T2- 50%	3.84	3.82	3.83	35.88	35.94	35.91	31.41	31.47	31.44	4.47	4.47	4.47
T3- 75%	3.83	3.81	3.82	36.16	36.21	36.19	31.66	31.71	31.69	4.50	4.50	4.50
S.E.m.±	0.05	0.05	0.03	0.23	0.22	0.16	0.24	0.31	0.19	0.04	0.05	0.03
CD (P=0.05)	NS	NS	NS	0.67	0.63	0.45	0.70	0.88	0.55	NS	NS	NS
B. NPK level of soil injection												
S0- 0%	3.97	3.91	3.94	33.57	33.73	33.65	29.22	29.32	29.27	4.35	4.41	4.38
S1- 25 %	3.91	3.87	3.89	34.68	34.79	34.74	30.28	30.34	30.31	4.40	4.45	4.43
S2- 50%	3.86	3.83	3.85	35.73	35.77	35.75	31.26	31.29	31.27	4.47	4.48	4.48
S3- 75%	3.82	3.80	3.81	36.54	36.68	36.61	32.04	32.19	32.11	4.50	4.49	4.50
S.E.m.±	0.05	0.05	0.03	0.23	0.22	0.16	0.24	0.31	0.19	0.04	0.05	0.03
CD (P=0.05)	NS	NS	NS	0.67	0.63	0.45	0.70	0.88	0.55	NS	NS	NS



4.3.3 Individual effect of injection method of NPK fertilization on total sugar of date palm cv. Halawy



4.3.4 Individual effect of injection method of NPK fertilization on reducing sugar of date palm cv. Halawy

Conclusion

Both trunk and soil injection methods of applying NPK significantly enhanced the fruit quality of date palm cv. Halawy. Trunk injection offered direct nutrient delivery to the vascular system, improving sugar content and reducing acidity, while soil injection ensured comprehensive nutrient availability to the root zone, resulting in slightly higher gains in TSS and sugar accumulation. The S3 treatment (75% NPK via soil injection) showed marginal superiority over T3 (75% NPK via trunk injection), making it a more effective approach for optimizing fruit quality under field conditions.

Declaration

The authors declare no conflicts of interest regarding this manuscript.

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 29. Table: 4.3.1 Individual effect of injection method of NPK fertilization on TSS, acidity and phenols of date palm cv. Halawy

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IMPACT OF ORGANIC MANURES AND BIO-FERTILIZERS ON ECONOMICS OF CULTIVATION OF DRAGON FRUIT (*HYLOCEREUS UNDATUS* L.) UNDER WESTERN UTTAR PRADESH CONDITIONS

Prashant Chauhan¹, Arvind Kumar², Sanjay Kumar Tripathi², Hariom Katiyar³, Vipin Kumar², Amit Kumar⁴, Sneha Gupta⁵ and Niharika Gurudev⁴

¹PG Research Scholar, ²Professor, ³Associate Professor, ⁴Ph.D. Research Scholar, ⁵Guest faculty,

College of Horticulture, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh, India.

*Corresponding Author Email-@gmail.com

Abstract

The field experiment entitled “Impact of organic manures and bio-fertilizers on economics of cultivation of Dragon fruit (*Hylocereus undatus* L.) under western Uttar Pradesh conditions” was carried out at Horticultural Research Centre, Sardar Vallabhbhai Patel University of Agriculture and Technology in Meerut, Uttar Pradesh during 2023. All the treatments were applied in randomized block design with three replications viz. T0- Control (No manures), T1- 100 % N as FYM, T2- 100% N as FYM + Jeevamrut + Panchagavya, T3 100% N as FYM+ NPK Microbial Consortium, T4- 100% N as FYM + Jeevamrut + Panchagavya + NPK Microbial Consortium, T5- 100% N as Vermicompost, T6- 100% N as Vermicompost + Jeevamrut + Panchagavya, T7-100% N as Vermicompost + Jeevamrut + Panchagavya + NPK Microbial Consortium and T8- 100% RDF. The results showed the use of treatment T7-100% N as Vermicompost + Jeevamrut + Panchagavya + NPK Microbial Consortium showed the highest gross return (Rs. 1173200/ha) and net return (Rs. 944479/ha) and B:C ratio (4.13). The maximum return and B:C ratio recorded in present study with the application of 100% N as Vermicompost + Jeevamrut + Panchagavya + NPK Microbial Consortium might be due to balanced dose of nutrients in terms of using Vermicompost, Jeevamrut, Panchagavya and NPK Microbial Consortium. This results in the best possible uptake of plant nutrients from the root zone and has a significant impact on the B:C ratio and net return.

Key Words: Dragon Fruit, Organic Manures, Bio-fertilizers, Vermicompost, Economics, B:C ratio

Introduction

Dragon fruit (*Hylocereus undatus* L.), also known as pitaya or kamalam, has gained considerable attention in recent years due to its high economic potential, nutritional value and adaptability to semi-arid and tropical climates (Yadav *et al.* 2024a). In India, particularly in Western Uttar Pradesh, the cultivation of dragon fruit has been expanding as farmers seek high-value crops that are both profitable and sustainable. The region's agro-climatic conditions

offer a favourable environment for the crop, yet optimizing cultivation practices to ensure maximum economic returns remains a key challenge (Wakchaure *et al.* 2021). While conventional farming practices have been widely used, there is a growing interest in sustainable agriculture, particularly through the use of organic manures and bio-fertilizers, which not only enhance soil health but also improve crop yield and quality (Yadav *et al.* 2024b). However, their specific impact on the economics of dragon

fruit cultivation in this region has not been thoroughly explored.

Organic farming practices, such as the use of farmyard manure (FYM), Jeevamrut, Panchagavya and microbial consortia, vermicompost and bio-fertilizers, have been reported to improve soil structure, increase microbial activity and provide balanced nutrition to plants (Biswal and Mishra 2024). These practices reduce the reliance on chemical fertilizers and pesticides, making them environmentally friendly and sustainable. However, while the agronomic benefits of organic inputs are well-documented, their economic impact on crop production, particularly on high-value crops like dragon fruit, remains under-researched. Farmers are often hesitant to adopt organic practices due to uncertainties regarding their profitability and the potential for high returns compared to conventional methods.

In Western Uttar Pradesh, where dragon fruit is being promoted as a lucrative crop, understanding the economic implications of using organic manures and bio-fertilizers is critical. The economic viability of these organic inputs needs to be assessed in terms of their ability to increase gross and net returns, as well as improve the benefit-cost (B:C) ratio, which is a key indicator of profitability in agriculture. Existing studies on dragon fruit cultivation have primarily focused on the effects of conventional fertilizers on yield and fruit quality, with limited attention given to the role of organic inputs in enhancing economic outcomes (Wakchaure *et al.* 2023; Jinger *et al.* 2024). Therefore, a comprehensive evaluation of the economic impact of organic manures and bio-fertilizers on dragon fruit cultivation is needed to provide a clear understanding of their potential benefits for farmers in this region.

This study aims to bridge this research gap by investigating the effect of organic manures and bio-fertilizers on the economics of dragon fruit cultivation under the specific agro-climatic conditions of Western Uttar Pradesh. The primary

objective is to evaluate the influence of these organic inputs on key economic parameters, including gross return, net return and the B:C ratio. By assessing the economic performance of different treatments, this study will provide valuable insights into the profitability of organic farming practices for dragon fruit and help farmers make informed decisions about adopting sustainable agricultural practices.

Materials and Methods

The field experiment was conducted on well-established dragon fruit orchards situated at Horticulture Research Centre of Sardar Vallabhbhai Patel University of Agriculture and Technology in Meerut, Uttar Pradesh, during 2023. Meerut district is situated in the Indo-Gangetic plains of India, with geographical coordinates ranging between 28°57' to 29°02' North latitude and 77°40' to 77°45' East longitude. The effect of organic manures and bio-fertilizers was noted on dragon fruit yield with 9 treatments and 3 replications.

Table 1. Detail of treatments

Notations	Treatments
T0	Control (No manures)
T1	100% Nas FYM
T2	100% Nas FYM + Jeevamrut + Panchagavya
T3	100% N as FYM + Microbial Consortium
T4	100% Nas FYM + Jeevamrut + Panchagavya + Microbial Consortium
T5	100% N as Vermicompost
T6	100% Nas Vermicompost + Jeevamrut + Panchagavya
T7	100% Nas Vermicompost + Jeevamrut + Panchagavya + Microbial Consortium
T8	100% RDF as inorganic

The total cost involving ploughing, layout, seedling, transplanting, weeding, irrigation, FYM, fungicide, harvesting, packaging and total working cost was calculated (Table 2). Then each treatment cost was calculated at following values

Table 2. Impact of organic manures and bio-fertilizers on Economics of treatments of Dragon fruit

Treatment	Particulars	Input	Rate (Rs.)	Total (Rs.)
T0	Control (No manures)			0
T1	FYM	22.2 ton/ha	100/qu.	22200
T2	FYM	22.2 ton/ha	100/qu.	22200
	Jeevamrut and Panchagavya	111.1 lit./ha	65/lit.	7221
	Total cost			29421
T3	FYM	22.2 ton/ha	100/qu.	22200
	NPK Microbial Consortium	22lit./ha	200/lit.	2400
	Total cost			24600
	FYM	22.2 ton/ha	100/qu.	22200
T4				
	Jeevamrut and Panchagavya	111.1 lit./ha	65/lit.	7221
	NPK Microbial Consortium	22lit./ha	200/lit.	2400
	Total cost			37821
T5	Vermicompost	22.2 ton/ha	300/qu.	66600
	Total cost			66600
T6	Vermicompost	22.2 ton/ha	100/qu.	66600
	Jeevamrut and Panchagavya	111.1 lit./ha	65/lit.	7221
	Total cost			73821
T7	Vermicompost	22.2ton/ha	100/qu.	66600
	Jeevamrut and Panchagavya	111.1 lit./ha	65/lit.	7221
	NPK Microbial Consortium	22 lit./ha	200/lit.	2400
	Total cost			76221
T8	100% RD of N	542 Kg urea/ha.	6/kg	3252
	100% RD of P	1444 Kg SSP/ha.	12/kg	17328
	100% RD of K	304 Kg MOP/ha.	33/kg	10032
	Total cost			30612

Economics of treatments

Cost of cultivation

To calculate the cost of cultivation, all input prices that were in effect at the time of usage, including labour expenses, were taken into account.

Gross income

The gross income was worked out based on the prevailing market price of dragon fruits.

Net return

The net return per hectare was calculated by using the following formula. $NR = \text{Gross income} - \text{cost of cultivation}$.

Benefit: Cost ratio

Using the provided formula, the benefit-cost ratio for various treatments was calculated based on the cost of the inputs used in cultivation as well as the price of marketable produce in the local market, and was expressed in ratio.

$$\frac{\text{Benefit: Net return (Rs./ha)}}{\text{Cost of cultivation (Rs./ha)}} = \text{ratio}$$

Result and discussion

The data on economics of treatments as influenced by application of different organic manures and bio-fertilizers are presented in Table 3 and Fig.1.

Total Cost of cultivation

In the present study, the highest cost of cultivation (Rs. 228721/ha) was recorded in treatment T7 (100%N as Vermicompost + Jeevamrut + Panchagavya + NPK Microbial Consortium) followed by T6 (Rs. 226321/ha), T5 (Rs. 21900/ha). However, the control shows the lowest cost of cultivation Rs. 154500/ha.

Gross return

The estimated values of gross income of various treatments varied from Rs.528240 to Rs.1173200/ha. The maximum gross income (Rs. 1173200/ha) was obtained from T7 (100% N as Vermicompost + Jeevamrut + Panchagavya + NPK Microbial Consortium) followed by T6 (100% N as Vermicompost + Jeevamrut + Panchagavya) Rs. 1064000/ha and T4 (100% N as FYM + Jeevamrut + Panchagavya + NPK Microbial Consortium) Rs. 954800/ha. The lowest gross return was recorded in control (Rs. 528240/ha).

Net return

Significantly higher net return (Rs.944479/ha) was recorded in T7 (100%N as Vermicompost + Jeevamrut + Panchagavya + NPK Microbial Consortium) followed by T6 (100% N as Vermicompost + Jeevamrut + Panchagavya) (Rs. 837679/ha). The lowest net return was registered in control (Rs. 375740/ha).

Benefit: Cost ratio (B:C)

The highest B:C ratio (4.13) was observed in treatment T7 (100% N as Vermicompost + Jeevamrut + Panchagavya + NPK Microbial Consortium) followed by T4 (100% N as FYM + Jeevamrut + Panchagavya + NPK Microbial Consortium) (4.02). However, the least B:C ratio (2.46) was noticed in treatment T0 (Control)

followed by T5 (100%N as Vermicompost) and T1 (100%N as FYM). The maximum return and B:C ratio recorded in present study with the application of 100% N as Vermicompost + Jeevamrut + Panchagavya + NPK Microbial Consortium might be due to balanced dose of nutrients in terms of using Vermicompost, Jeevamrut, Panchagavya and NPK Microbial Consortium. This results in the best possible uptake of plant nutrients from the root zone and has a significant impact on the B:C ratio and net return. The results are also so in conformity with the finding of **Binepal *et al.*, (2013)** in Guava and **Rashmi (2019)** in Dragon fruit. Contradictorily, the lowest B:C ratio observed in the treatment with 100% FYM or vermicompost may be attributed to the higher cost associated with these organic manures. Similar observations were also reported by Shivakumar (2010), Yadav *et al.* (2011b) and Agarwal and Sahu (2021) in papaya.

Table 3. Effect of organic manures and bio-fertilizers on Total Cost of Cultivation, Gross return, Net return and B:C ratio of Dragon fruit

Treatments	Total Cost of Cultivation (Rs. /ha)	Gross return (Rs. /ha)	Net return (Rs. /ha)	B:C ratio
T0	152500	528240	375740	2.46
T1	174700	771400	596700	3.42
T2	181921	819000	637079	3.50
T3	177100	844200	667100	3.77
T4	190321	954800	764479	4.02
T5	219100	912800	693700	3.17
T6	226321	1064000	837679	3.70
T7	228721	1173200	944479	4.13
T8	183112	906440	723328	3.95

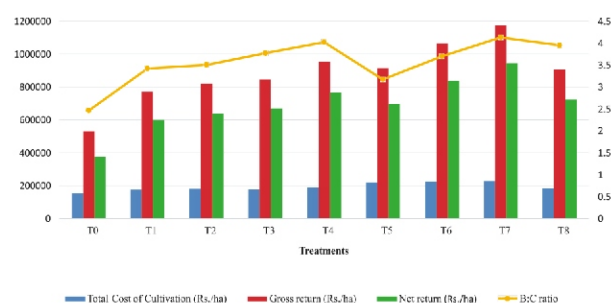


Fig.1. Effect of organic manures and bio-fertilizers on Total Cost of Cultivation, Gross return, Net return and B:C ratio of Dragon fruit

Conclusions

From the present investigation, it is concluded that the treatment T7-100% N as Vermicompost + Jeevamrut + Panchagavya + NPK Microbial Consortium showed the highest gross return (Rs. 1173200/ha), net return (Rs. 944479/ha) and B:C ratio (4.13). These findings imply that using organic manures and bio-fertilizers in dragon fruit growing might improve sustainability and efficiency in western Uttar Pradesh, benefiting producers and the environment.

Authors Contribution

In the preparation of my manuscript, all authors played an important role in providing valuable suggestions and ideas for improving its content and structure. Their contributions helped to refine the research findings and to present them in a clear and concise manner. This collaborative effort demonstrates the authors' commitment to producing a high-quality manuscript that accurately represents the research findings and contributes to the scientific community.

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PROLIFIC CONTRIBUTION OF MICROBES IN HEAT STRESS MITIGATION IN PLANTS

Viabhav Kumar Upadhayay¹, Damini Maithani^{2*},

Ashish Kumar³, Hemant Dasila⁴, Yogesh DashrathNaik⁵

¹Department of Agricultural Biotechnology and Molecular Biology, College of Basic Sciences and Humanities, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur- 848125, Bihar, India.

²Department of Natural Resource Management: Plant Microbiology, College of Horticulture, Sardar Vallabh Bhai Patel University of Agriculture & Technology, Modipuram, 250110, Meerut, India.

³Department of Microbiology, College of Basic Sciences and Humanities, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar-263145, U.S. Nagar, Uttarakhand, India.

⁴Department of Microbiology, Akal College of Basic Science, Eternal University, Himachal Pradesh, India.

⁵Department of Agricultural Biotechnology and Molecular Biology, College of Basic Sciences and Humanities, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur- 848125, Bihar, India.

*Corresponding Author Email-daminimaithani27@gmail.com

Abstract

In the present scenario, the heat stress (HS) is being prominent, affecting the agricultural system through showing negative impacts on plant growth. There are numerous traditional tactics, including plant breeding and genetic engineering, that have been used to circumvent the impact of HS on crops. However, using agriculturally important microbes provides sustainable and green strategies as substitutes. Agriculturally important microbes encompass rhizospheric microbes, endophytes and mycorrhizal fungi, which, besides showing plant growth promoting traits also augment the heat tolerance in plants. The synthesis of exopolysaccharides (EPS) and ACC deaminase are imperative mechanisms of these microbes for alleviating the effect of various abiotic stresses. As potential plant probiotics, these microbes exhibit various plant growth stimulatory effects such as nitrogen fixation, solubilization of nutrients, production of siderophore, ammonia, HCN and plant growth hormones. However, heat stress adapting microbes possessing multifarious plant growth stimulatory effects as bioinoculants can improve the plant resilience under heat stress by enhancing photosynthetic activity and strengthening antioxidant defence system. In this chapter, we illustrate the functional application of rhizo-microbes, endophytes and as well mycorrhiza in terms of alleviation of heat stress. In the current era of climate change, using microbes exerts an eco-friendly, and cost-effective approach for encouraging sustainable agricultural practices.

Key Words: Antioxidant defense system, arbuscular mycorrhizal fungi (AM fungi), Climate change, Heat stress (HS), rhizo-microorganisms, endophytes

Introduction

In the face of climate change, HS is an imperative instance of abiotic stress, which results from an increased ambient temperature and is associated with irreversible damages to plants. The devastating effects of HS are majorly studied

in terms of reducing crop growth and productivity. However, the degree of adaptation differs relying on the temperature and plant development stages (Ahmad et al., 2022). Characteristically, HS can be considered as the temperatures above 75 °F (around 24°C), and hence this elevation in

temperature can lead to the disruption of physiological processes throughout the growth cycle (from germination to harvest). The devastating heat stress effect can be seen as reduced crop yields, visible damage such as 'wilting' and 'leaf injury', as well as fruit drop. Extended exposure to higher temperatures may cause severe cellular damage, eventually endangering the endurance and quality of plants (Shaffique et al., 2022). In temperate areas, HS is notoriously harmful during key growth periods (like "anthesis" and "grain filling"), and the major rabi varieties in India (such as wheat, mustard, barley, sesame, and peas) are among the cereal crops most susceptible to temperature fluctuations (Mitra et al., 2021). The negative impacts of HS on plants can be seen as deterioration of the physiological activities of plants which ultimately affects the plant growth parameters and shows a reducing pattern in yield attributes (Ali et al., 2011). However, there are various strategies to combat HS effect. These include conventional plant breeding approaches, biotechnological methods, and molecular techniques to develop heat-tolerant plant varieties. In recent days, the omics approaches provided a better insight regarding molecular mechanisms behind heat tolerance in plants (Hassan et al., 2021). However, enhancement in HS tolerance in plants is also carried out by adaptive crop management practices (like optimizing planting times, seed preparation, nutrient and water management, and use of osmosis inhibitors) (Hassan et al., 2021; Kumari et al., 2021). But, the application of agriculturally important microbes with traits like 'heat stress adaptation' and 'plant growth promoting activities' can be a ecofriendly solution for alleviating the drastic effect of heat stress (Mukhtar et al., 2020; Shaffique et al., 2022). Such microbes can be used as potential bioinoculants for crops due to their beneficial characteristics, which are manifested in terms of augmentation of plant growth and improvement of stress tolerance in plants under challenging environmental conditions (Adeleke et al., 2024). Rhizospheric microorganisms, endophytic microbes and AM fungi form symbiotic or associative interaction with plants and studies have elucidated their functional role in improving heat stress tolerance in plants (Cabral et al., 2016; Khan et al., 2020a;

Ahmad et al., 2022). The microbial strains isolated from rhizosphere or plant tissue and screened for several characteristics like adaptability to abiotic stress and plant growth stimulating activities can be used as potential bioinoculants for crops. These can act as promising "biostimulants" as they provide numerous benefits to plants and can help plants for acquire resilience to biotic and abiotic stresses (Sarkar et al., 2018; Barghi and Jung, 2024). The word "biostimulants" here can be illustrated as substances and/or microbial agents that exhibit beneficial contributions to plant growth via improving nutrient uptake, crop quality, and stress tolerance (Calvo et al., 2014; Duarte et al., 2014). The plant growth promoting attributes of these biostimulants are evident through numerous activities like nitrogen fixation, synthesis of phytohormones, solubilization of nutrients (like phosphorus, zinc, potassium), synthesis of EPS, production of iron chelating compounds (siderophores), etc., under HS (Hakim et al., 2021). Plants inoculated with microbes have shown improvement in physiological properties, manifested by improvement in photosynthetic activities, osmolytes accumulation, activation of antioxidant defence system, reduction of MDA and reactive oxygen species (ROS) (Sarkar et al., 2018). However, beneath the ground, arbuscular mycorrhizal fungi (AMF) make symbiotic interactions with plant roots, act as co-transporter of phosphorus to plants, and are also suggested as prominent agents for reducing the impacts of abiotic stress on plants (Upadhayay et al., 2019). AMF have displayed a variety of functional contributions such as enhancing in photosynthetic processes, nutritional uptake, and secondary metabolite accumulation, regulating oxidative defense systems, and maintaining osmotic balance within plants under environmental stress conditions (Maya and Matsubara, 2013; Ahamd et al., 2022). In the present article, the prolific contribution of microbes as potential biostimulants in terms of providing heat tolerance in plants is elucidated, and it also emphasizes practicing sustainable agriculture through application of agriculturally important microbes as potential plant probiotics under climate change scenarios.

Heat Stress and its effect on plants

The worldwide temperature rise due to the climate changes so it is extremely important to study impact of HS in agriculture crops. HS can be defined as elevation in temperature above the threshold level for a adequate time period to create irreversible damage to plant. This causes significant threat to global crop productivity and food security (Mishra et al., 2023). The average worldwide temperatures could increase by 1.5 to 4.8 °C by the end of this century which leads to severe implications for agriculture yield and quality (Bokshi et al., 2022). The studies predicts up to 18.1% by 2050 decrease in wheat yields by 2050 due to the terminal HS (Dubey et al., 2020). Moreover, decrease in yield also projected for other major agricultural crops. The expected reduction will also be seen due to increase in temperature for other major crops like 7.3% in maize, 6.1% in rice, 3.2% in wheat and 3.0% for soybean (Zhao et al., 2017). As a result of this, it is necessary to understand the effect of HS on crops to find out efficient approaches to limit the damage. Plant face various challenges during HS including decline in nutrient uptake, reproductive process and other quality parameters such as cellular damage, affecting membrane integrity and enzyme activity by disrupting essential physiological and biochemical processes (Hasanuzzaman et al., 2013). The severe effects of HS depend on its timing, duration, and intensity. As the optimal temperatures for growth and function varying based on the plants developmental stage. Plants are affected by HS during vegetative stages (such as stem elongation, tillering and seedling growth). Further, its impact is more severe at the time of reproductive stages (such as flower initiation, grain filling and fertility) (Groli et al., 2024). Particularly, reproductive stage is more vulnerable to elevated temperature which results in decline in pollen viability and set of seeds, leading to decrement in yield (Resentini et al., 2023). Beena et al. (2018) studied severe effects of HS (6–8 °C above ambient) on 29 rice cultivars and found decline in chlorophyll content and net photosynthetic rate. They also found increased transpiration rate, stomatal conductance and specific leaf area. For surviving in HS environment plants have to

develop adaptive mechanisms. The major physiological changes as adaptive mechanism are changes such as enhanced transpiration rates, alterations in leaf orientation and the synthesis of heat shock proteins, these help to protect plant cellular structures from damage (Jagadish et al., 2020). Furthermore, cellular membranes and proteins under stress condition are stabilize by accumulate osmoprotectants like proline and glycine betaine (Bita and Gerats, 2013). HS impact extends beyond mere survival by affecting nutritional quality of crops (Jha et al., 2024). It also declines essential nutrients and phytochemicals vital for animal health (Mishra et al., 2023). Understanding these complex interactions between HS and plant responses is significant for develop effective strategies to boost crop resilience and preserve food quality in a world facing problem of global warming.

Strategies for Managing Agriculture Under Heat Stress

Application of Inorganic Amendments

The guaiacol peroxidase is selenium (Se) containing enzyme at its active site having antioxidant properties, makes it an essential component of nutrition for plants and animals. Se application in plants shown enhanced resistance to variety of environmental stresses such as heat, drought and heavy metals (Iqbal et al., 2015, Ikram et al., 2020, Feng et al., 2021). Additionally, utilizing Se has had upregulated impact on plant productivity and development under heat stress conditions. Balal et al. (2016) demonstrated that foliar application of 8 mM of Se enhanced physiological parameters (photosynthetic rate, stomatal conductance, and transpiration rate) in cucumber plants exposed to HS at day temperature 40°C and night temperature 30°C. It has been demonstrated that applying Se externally raised antioxidant activity and chlorophyll content while lowering MDA, H₂O₂, and electrolyte leakage (Haghighi et al., 2019; Seliem et al., 2020). The Calcium (Ca²⁺) contributes to plant resilience against stress by activating various biochemical pathways, either individually or in combination (Fan et al., 2023). Lakaew et al. (2021) examined the impact of

growing season and foliar application of calcium acetate (CA) on rice yield under ozone (O_3) and HS. Pretreatment with 5 mM calcium acetate activated ascorbate peroxidase (APX), lowered malondialdehyde (MDA), and boosted NADPH and chlorophyll content, leading to improved yields under combined O_3 and heat stresses. Magnesium (Mg^{2+}), an essential macronutrient and the second most abundant free divalent cation in plants, is vital for numerous physiological processes that drive plant growth and development (Zahra et al., 2023). Rodrigues et al., (2021) investigated the effects of foliar application of Mg on soybean and maize, and they found that Mg supplementation improved photosynthesis, rubisco activity, and antioxidant metabolism, which enhanced gas exchange, reduced oxidative stress, and increased grain yield. Altaf et al. (2021) found in their research that adequate amount of sulfur administration in HS plants improved biomass and growth by reducing reactive oxygen species and increasing chlorophyll content as compared to sulfur deficient plants. The inadequate amount of zinc significantly reduced growth of plant while an adequate zinc supply helped to prevent the negative effects of HS (Umair Hassan et al., 2020).

Application of Organic Amendments

A wide range of organic amendments (compost, manure, crop residues and biochar) has been used to reduce abiotic stress in crops (Guo et al., 2020). The combined application of mineral fertilizer such as phosphorus with biochar has shown promising effects in reducing HS in crops (Yadav and Ramakrishna 2023). Wang et al. (2021) investigated heat protection through examining soil canopy in which they have apply different organic materials such as biochar and organic fertilizer. In Experiment I, higher temperatures at the reproductive stage in 2018 resulted in a 25 - 32% reduction in grain weight compared to 2017. The application of biochar (BC) increased grain weight by 15% in Experiment II (2019), whereas organic fertilizer (OF) increased grain weight by 7%, mostly as a result of better soil water content. Both treatments successfully reduced soil and canopy temperatures, significantly increasing photosynthesis and also improving the soil's

ability to retain water (by 8% for BC and 5% for OF). Singh et al. (2020) studied the effects of rice husk ash (RHA/biochar) and farmyard manure (FYM) on wheat grown in silty clay soil. Their results showed that plant biomass was highest with FYM, showing an increase of 11 - 31%, while the lowest biomass was observed with RHA alone, increasing by only 6%. Furthermore, photosynthesis rates were significantly higher in FYM treatments, with increases of 5 - 26%, while RHA alone and combined RHA + FYM treatments had lower rates, decreasing by 2 - 15%.

Use of Grafting and Rootstock Techniques

An extremely successful strategy for overcoming biotic or abiotic stress factors and soil-borne diseases is plant grafting. It eliminates the need for crop rotation, increases yields under difficult conditions, extends the growing season, reduces the need for agrochemicals and fertilizers, and enables the widespread use of a variety of phytogenetic resources as rootstocks (Oyebamiji et al., 2024). Grafting is a special form of asexual propagation in which a part of a plant, called a scion, is joined to another plant, the rootstock. Through this process, both parts grow together into a single plant with a common vascular system. Typically, the rootstock and scion are selected from different plant species to combine their desirable characteristics. At the transplant site, tissues of the shoot and rootstock unite and form the new plant structure (Singh et al., 2020). Grafting technique is a widely utilized for propagating various important fruit crops (citrus, apricots, apples, avocados, peaches, plums and almonds) (Yang et al., 2022). This technique has been recently applied to various vegetable crops (Singh et al., 2020). According to Shehata et al. (2022), they grafted cucumbers and found improve agronomic parameters (leaf area and total yield). The physiological studies demonstrated that grafted cucumber showed elevated amount of antioxidant enzyme activity, proline accumulation and stress response gene expression in comparison to non-grafted controls under both normal water as well drought conditions. This study highlights grafting as a potential but time consuming technique in modern agriculture that requires careful planning and implementation.

Plant Breeding

New plant varieties are developed through plant breeding techniques by selecting individuals with desirable traits or by crossing closely related plants to merge their traits. Plant breeding can be done by transfer of pollen from one plant that has beneficial characteristics to another variety of plant that also has desirable trait (Suanno et al., 2021). Selective offspring breeding can be done to discover a new variety with the desired traits. However, this practice is complex because desirable traits can be associated with unfavorable traits due to random DNA recombination from the wild plants. To acquire specific trait to obtain high performance variety at least six generations selective breeding is required (Lamichhane and Thapa 2022). For example, to impart resistance from abiotic stress to produce high yielding variety, it is important to crossed and the elite parent is backcrossed repeatedly to maintain the genetic potential of newly introduced stress resistance allele. It typically takes many generations to secure the resistance allele. It takes around 12 to 15 years for a new crop variety to come to the market, depending upon crop species (Atlin et al., 2017). Therefore, it needs a innovative approaches to speed up the development of improved crop varieties to survive in heat stress condition.

Genetic Engineering

To increase plant resistance to various environmental stresses one of the modern methods is genetic engineering. This techniques works by transferring osmolyte producing gene from stress resistant plant to increase plant resistant from stresses (Parmar et al., 2017). For example, Roy-Barman et al. (2017) transferred a cDNA clone of the BADH (betaine aldehyde dehydrogenase) gene from a HS tolerant spinach plant to tomato plants through Agrobacterium-mediated transformation. Additionally, they also compare the genetically modified tomato plants under HS with non-transgenic plants and found that increased heat tolerance due to the transfer of BADH gene, which enhanced glycine-betaine accumulation, photosynthesis efficiency, reduced production of ROS, and increased antioxidant activity. Song et

al. (2014) found improved heat tolerance *chrysanthemums* with overexpressed *CgHSP70* genes. In the transgenic lines with overexpressed *CgHSP70*, proline levels, peroxidase POD activity were higher as well as MDA content was found lower. These advancements are continued to disclose and offer potential strategies for developing more stress resilient crops and ultimately contribute to promising agricultural practices in the face of various environmental challenges.

Random Mutation

The random mutagenesis is well recognized and unrestricted technique for increasing crop diversity. Mutations could be induced by physical mutagens (gamma rays, neutrons, and X-rays), chemical mutagens also induce mutation by including base analogues (bromuracil), intercalating compounds (ethidium bromide), alkylating agents (ethyl methanesulfonate) (Sawarkar et al., 2023). In comparison to physical mutagens, chemical mutagens are used less frequently. Physical mutagens such as radiation offer an advantage over chemical agents such as EMS, which can often cause mutations. This is because radiation causes a greater proportion of mutations that have significant effects on gene functions, such as complete gene deletions, resulting in fewer genome-wide mutations and more loss-of-function mutations (Alam et al., 2022). Inducing mutation is incredibly potent technique to generate novel and distinctive plant germplasm. Plant mutation breeding is one of the most widely used and superior technique for rapid production of mutant varieties. It is less time consuming than conventional breeding technique (Ahmar et al., 2020). By using a selective medium, in vitro selection in the breeding of plant mutants allows the creation of genotypes resistant to harsh environmental factors such as drought, excessive salt or the presence of pathogens (Viana et al., 2019). It is simpler and more reliable than greenhouse or field testing because biological materials treated with mutagens can be efficiently evaluated in a compact in vitro environment. Purified lines that exhibit the desired characteristics can then be used for further breeding or mass production.

Application of Beneficial Microbes

Rhizospheric microbiota (composed of bacteria and fungi) play a crucial role in increasing plant development and productivity while improving tolerance to environmental stresses. These microbes initiate molecular signaling networks that regulate phytohormone levels and gene expression. This mechanism also activates all stress-responsive signaling pathways such as accumulation of osmolyte, nutrient, increase antioxidant activity and promote ion transport (Khan et al., 2019). Microbes produce exopolysaccharides which hold water and enhance soil structure during HS (Naseem et al., 2018). This water retention and production of compounds like proline and glycine betaine plays a role in regulating heat stress tolerance in plants (Zulfiqar et al., 2022). The bacteria found in rhizosphere are known as Plant growth-promoting rhizobacteria (PGPR) which can produce phytohormones like auxin that stimulates root and shoot growth and cytokinins which promote cell division and differentiation (Oleńska et al., 2020). PGPR can also produce siderophores, improve nutrient mobilization by solubilizing phosphate and fixation of nitrogen (Upadhayay et al., 2022a, 2022b). PGPR can boost plant levels of abscisic acid (ABA), enhancing the expression of heat tolerance genes that increase osmoprotectants and K^+ accumulation, reduce electrolyte leakage, and improve reactive oxygen species (ROS) scavenging (Li et al., 2020). Inoculating plants with PGPR containing 1-aminocyclopropane-1-carboxylate (ACC) deaminase lowers ethylene levels and supports plant growth and yield under heat, drought and salt stress conditions (Duan et al., 2021). The enzymes necessary for photosystem II may be deactivated by HS, which lowers the rates of photosynthesis. On the other hand, during HS, oxygenic bacteria with light-harvesting pigments rewire cellular functions inside the thylakoid membrane to facilitate the absorption of carbon dioxide and the release of oxygen (Liu et al., 2019). Particularly in these circumstances, cyanobacteria facilitate photosynthesis and encourage plant development (Nawaz et al., 2024). The rise in temperatures cause cellular respiration to speed up because of the higher kinetic energy, but a large portion of this energy is used to maintain

respiration, which reduces the total energy efficiency of plants. Beneficial bacteria improve the cycling of nutrients in plants and increase soil respiration. These microorganisms can aid in stress reduction and ecological stabilization, and interactions between plants and microbes are essential for preserving the amounts of nitrogen, hydrogen, sulphur, and oxygen in the biogeochemical cycle (Wang et al., 2024). “Abscisic acid (ABA)”, often denoted to as the “stress hormone,” plays a key role in regulating plant responses to numerous stress conditions. It is mainly crucial in helping plants cope with both biotic stresses (such as pathogen attacks), and abiotic stresses (like drought and extreme temperatures). This phytohormone is synthesized in response to interactions between microbes and plants. PGPR produce ABA which result in coordinate stomatal closure in plants during heat stress conditions. This process is crucial for osmoregulation and preservation of water loss through evaporation (Sah et al., 2016). Fungal group such as *Trichoderma* and arbuscular mycorrhizal (AM) fungi are important category of soil microorganism also reduce the impact of HS by enhancing root development, membrane integrity, nutrient and water uptake (Begum et al., 2019). These fungi maintain water use efficiency under stress condition by promoting osmolyte accumulation, scavenging reactive oxygen species, stimulating gene expression of aquaporins and membrane transporters and activating phytohormone signaling (Mishra et al., 2023). Inoculation of these beneficial microorganism in plants provide enhanced resistance and tolerance to HS. Therefore, it is necessary to study advantageous microbial population associated with plants. There isolation and characterization can be tremendously significant for inoculating plants to increase their tolerance to various abiotic stresses. Further research in this area is critical to creating sustainable agricultural practices that increase crop productivity and promote environmental stability in the face of climatic challenges.

Utilization of microbes as an alternative approach for mitigating heat stress in plant

Heat stress (HS) poses a major environmental challenge that negatively affects plant growth,

productivity and survival. As the global temperatures rise due to climate change, traditional methods for enhancing HS tolerance in plants, such as breeding and genetic engineering, face significant challenges. These challenges include longer timelines for development, high financial costs and various environmental limitations. Microbial strategies indicate a promising, eco-friendly, and cost-effective approach to mitigate “heat stress” and enhance plant tolerance. Plant growth-promoting microorganisms (PGPM), which include bacteria, fungi, and algae have proven efficient in improving plant stress tolerance. Plants employ various adaptation strategies that help them to deal with increased temperatures, which contribute in enhancing their thermotolerance through several mechanisms. Among these, the synthesis of heat shock proteins (HSPs), antioxidant enzymes, exopolysaccharides, and bioactive metabolites plays a significant role. Certain bacteria such as *Pseudomonas putida* are known to produce HSPs that play a crucial role in plant to cope with thermal stress. These HSPs function by stabilizing cellular structures and facilitating recovery after exposure to stress (Ali et al., 2011). Microorganisms can induce significant structural modifications in plants that lead to a phenomenon known as induced systemic tolerance (IST). This process enhances the plant’s ability to deal with prolonged heat exposure (Yang et al., 2009). PGPM are involved in the production of phytohormones such as auxins, cytokinins, gibberellins and abscisic acid (ABA), which play a crucial role in regulating plant growth and stress responses, thereby improving the plant’s ability to resist HS (Ahmad et al., 2022). The advantage of microbial inoculation exists in its capability to enhance the antioxidant defense mechanisms within plants. Microbial inoculants enhance plant to survive under oxidative stress and various environmental challenges by promoting the activity of various protective enzymes. Under heat stress conditions, plants often produce excessive reactive oxygen species (ROS), which can cause oxidative damage. PGPM play a critical role in regulating ROS levels by increasing the activity of key antioxidant enzymes, including catalase (CAT), superoxide dismutase (SOD), and ascorbate peroxidase (APX). These all antioxidant

enzymes are important for mitigating oxidative stress and protecting plant cells from damage. The application of *Bacillus cereus* SA1 to tomato plants has been shown to significantly enhance the activity of various antioxidant enzymes, thereby improving the plant’s capacity to scavenge harmful ROS and increasing chlorophyll efficiency under heat stress conditions (Khan et al., 2020). Inoculation of wheat with *Pseudomonas putida* strain AKMP7 significantly increases the activity of antioxidant enzymes, protecting plant against oxidative damage and mitigating cellular damage during HS (Ali et al., 2011). The synthesis of exopolysaccharides (EPS) by heat-tolerant PGPM provides an additional protective mechanism against HS. EPS form protective biofilms on the root surfaces, which enhance moisture retention, improve nutrient absorption, and protect plant roots from thermal damage. These biofilms also act as chemoattractants, promoting a stable microenvironment that supports the survival of both plants and microbial communities under extreme environmental conditions. In one study tomato plants inoculated with exopolysaccharides producing *Bacillus cereus* which has been shown to increase root and shoot length, chlorophyll content and total biomass, thereby improving overall plant growth and survival under heat stress condition Mukhtar et al. (2020). PGPM having adaptive capabilities for tolerance of HS by formation of protective biofilm. These biofilm forming microbes prove HS resilience to plant through enhanced antioxidant activity and phytohormone levels. These microbes can serve as sustainable alternative to conventional environmental stress management technique in plants.

Microbial Contributions to Heat Stress Mitigation in Plants

Globally, detrimental effect on plant productivity has been shown by HS as a compelling abiotic stress. The increase in temperature can lead to various abnormalities in morphological, physiological and metabolic pathways. Researchers are also seeking eco friendly biological solutions to address the serious issues engendering from climate change. They are considering the negative consequences of a climate change scenario. The modern agricultural research investigate advantageous microorganism

to increase HS endurance in plants as fascinating and cutting-edge topic. The use of these advantageous microorganisms is a hot topic of research where certain studies explored the microbial-assisted HS tolerance in plants. Reducing the abiotic stress effect on plants, such as heat and cold, and improving overall plant productivity depend on the interaction between plants and soil microbiota (PGPR and arbuscular mycorrhizal fungi) and plant-associated microbes (such as bacterial and fungal endophytes). These microbes promote the synthesis of essential phytohormones, secondary metabolites, organic acids and amino acids to help plants overcome the negative effects of HS (Chouhan et al., 2023). Microbial inoculants such as endophytes, rhizospheric microbes and mycorrhiza all make a positive contribution to reducing HS in plants as described in the following sections.

Endophytic Microbes: Protectors Against Heat Stress

Endophytic microorganisms are associated with plants and inhabit within leaves, stems, roots and other internal tissues without harming the host or causing disease. These microbes colonized in various plant structures like apoplast, intercellular spaces and xylem vessels, etc. Endophytes have been isolated and studied from a various plant part, such as roots, stems, leaves, flowers, fruits, and seeds (Ameen et al., 2024). They play noteworthy roles in enhancing plant development, fitness, and adaptability. Endophytes exhibit various plant growth-promoting mechanisms such as nitrogen fixation, production of phytohormones such as indole-3-acetic acid (IAA), and synthesis of other growth regulators, thereby contributing to plant growth (Upadhayay et al., 2022a). Their role in stress reduction is also unraveled as studies have demonstrated their role in improving plant resilience by promoting growth and protecting against abiotic stresses such as heat, salinity, and drought. Their ability to successfully colonize plant tissues—coupled with attributes like mobility, cell wall degradation capacity, and reactive oxygen species scavenging—enables them to effectively support plants in overcoming the detrimental effects of climate change (Godara and Ramakrishna, 2023). *Bacillus cereus* SA1, a

thermotolerant endophyte, significantly enhanced soybean resilience under HS by increasing biomass, chlorophyll content, and antioxidant activity while sustaining the expression of the critical heat shock protein gene *GmHSP*, reducing abscisic acid levels, and activating stress-responsive genes *GmLAX3* and *GmAKT2*. This indicates a promising mechanism for HS mitigation and potential biofertilizer use (Khan et al., 2020b). The isolation and screening of abiotic stress-resistant endophytic bacteria, *Staphylococcus epidermidis* CK9 and *Bacillus australimaris* CK11, from *Commiphora gileadensis* significantly enhanced tomato growth and photosynthetic pigments (chlorophyll a, b, and carotenoids) while maintaining a high K^+/Na^+ ratio under heat, salinity, and drought stress. These strains also boosted antioxidant enzyme activity (catalase and peroxidase), upregulated Glutathione reductase and CAT gene expression, and promoted phytohormonal balance by downregulating abscisic and jasmonic acids while stimulating salicylic acid (Jan et al., 2024). Co-inoculation of the ACC deaminase-deficient mutant strain of *Rhizobium leguminosarum* with non-rhizobial endophytes (*Phyllobacterium salinisoli*, *Starkeya* sp., and *Pseudomonas turukhanskensis*) improved pea growth and symbiosis under HS by enhancing biofilm formation and modifying phenolic content in root exudates (ben Gaied et al., 2024). The isolation of the endophytic fungus *Aspergillus japonicus* EuR-26 from *Euphorbia indica* L. demonstrated its potential to alleviate HS in soybean and sunflower plants by enhancing growth characteristics and improving nutritional quality, as well as modulating the activities of key stress-related hormones and enzymes under high temperatures (40°C). This suggests its applicability as a thermal stress alleviator in arid and semi-arid regions (Ismail et al., 2018). The thermophilic endophytic fungus CpE, isolated from *Cullen plicata* roots, demonstrated potential for enhancing HS tolerance in cucumber plants by improving photosynthetic efficiency, water-use efficiency, and root growth while significantly increasing the accumulation of total sugars, flavonoids, saponins, and antioxidant enzyme activities (Ali et al., 2018). Additionally, the endophytic fungus *Paecilomyces formosus* LWL1,

known for producing phytohormones and various secondary metabolites, significantly enhanced plant growth attributes in japonica rice, including plant height, fresh weight, dry weight, and chlorophyll content. Furthermore, *P. formosus* LWL1 provided protection against HS compared to control plants, as indicated by reduced levels of stress-signaling compounds such as abscisic acid (25.71%) and jasmonic acid (34.57%), alongside an increase in total protein content (18.76%–33.22%) (Waqas et al., 2015).

Rhizospheric Microbes: Enhancers of Plant Resilience under heat stress

The rhizospheric area is a vibrant zone around the plant root characterized by strong microbial activities that significantly influence plant growth. Microbes, that are dwelling in this environment, can either have a positive effect on plants or a certain group can be harmful to plants. Among them, plant growth promoting rhizobacteria (PGPR) are a group of bacteria that improve plant health and growth through various mechanisms (Upadhayay et al., 2023a, 2024). The exudates and metabolites secreted by plants serve as important resources that attract beneficial microbial communities (Upadhayay et al., 2022a). PGPR directly improves plant growth through a multifarious mechanism. These comprise nitrogen fixation, solubilization of nutrients (such as phosphorus, potassium, zinc, etc.), and production of phytohormones (such as auxins, cytokinins, and gibberellins) (Khan et al., 2023, 2024; Upadhayay et al., 2022b, 2023b, 2023c). However, PGPR indirectly alleviates biotic stress by producing siderophores and inhibiting pathogenic organisms (Bhat et al., 2022; Voccianti et al., 2022; Jaggi et al., 2023). In plethora of studies, PGPR has been increasingly recognized as an effective agent for increasing plant tolerance to abiotic stresses such as drought, salinity and heavy metal toxicity (Singh et al., 2022; Upadhayay et al., 2023b). This is particularly important in the context of climate change and global food security issues (Zhang et al., 2023). ACC deaminase-producing PGPR can reduce ethylene levels by converting ACC to two compounds namely α -ketobutyrate and ammonia. This mitigates the lethal effects of ethylene on plant growth during heat stress. Inoculation of ACC deaminase-producing PGPR in plants

increase tolerance to abiotic stresses (Mukhtar et al., 2020). Furthermore, PGPR-mediated reduction of HS is associated with several physiological parameters, including reduced reactive oxygen species (ROS) production, reduced membrane damage, maintenance of chloroplast integrity, increased chlorophyll content, increased expression of redox enzymes, and osmolyte accumulation - all contributing to improved thermotolerance in plants (Sarkar et al., 2018). Ashraf et al. (2019) studied four PGPR *Pseudomonas brassicacearum*, *Bacillus thuringiensis*, *B. cereus* W6 and *B. subtilis* derived from rhizosphere of both heat-stressed and non-stressed wheat genotypes and found that *P. brassicacearum* inoculation in plant significantly improve plant parameters such as root and shoot fresh weight as well as antioxidant enzyme activity and protein content. Another study found that common beans (*Phaseolus vulgaris* L.) under HS at 35 °C showed significantly improved growth and reproductive performance after inoculation with *Bacillus subtilis* (two strains “AP-3” and “AP-12”). This resulted in augmented shoot biomass, leaf number, pod production, and reduced flower abortion rates (de Lima et al., 2022). Furthermore, *Bacillus cereus*, known for its heat tolerance, improved tomato development under HS by increasing shoot and root length, leaf surface area, and total biomass, while mitigating HS effects through increased synthesis of extracellular polymeric substances (EPS) and ACC-deaminase activity (Mukhtar et al., 2020). In eggplants, high-temperature-tolerant PGPR inoculation also markedly reduced the effects of HS by increasing ACC deaminase activity while promoting EPS accumulation (Hannachi et al., 2024). *Bacillus mycoides*, isolated from bamboo rhizosphere soil, produced phytohormones like IAA and gibberellic acid (GA), which increased root architecture and photosynthetic efficiency in *Arabidopsis thaliana* seedlings. In addition, this bacterium also upregulate genes (*SARD1*, *CBP60G*, *DREB2A*, *HsFA2*, *MYC2*, *LOX1*), antioxidant activity (catalase) and ascorbate peroxidase (APX), which provide resistance to thermal and drought stress (Kurniawan and Chuang, 2022). Macabuhay et al. (2022) found that bacterization of *Arabidopsis thaliana* with *Paraburkholderia phytofirmans* PsJN enhance

root and shoot growth under heat stress condition. The magnitude and timing of these effects varied depending on root type and temperature conditions, providing insights into the intricate relationship between plants, microbes and their surroundings. Additionally, study also observed that high temperature tolerant PGPR significantly attenuates the adverse consequences of HS on *Solanum melongena* L. via the synthesization of ACC deaminase. It increased the accumulation of exopolysaccharides while facilitating the conversion of ACC to -ketobutyrate and ammonia, eventually improving both morphological and physiological parameters (Sami et al., 2024). Mukhtar et al. (2022) showed that *Bacillus Safensis* T6, as another promising heat-tolerant PGPR strain, significantly increased flower and fruit production in tomatoes under HS conditions through its phytohormone production ability. Furthermore, “*Thuricin 17* (Th17)”, a signaling molecule produced by *Bacillus thuringiensis* NEB17, proficiently reduced drought combined with heat stress in canola (*Brassica napus* L.) through improving leaf area expansion, biomass accumulation, root development, and enhancing antioxidant enzyme activities—demonstrating the

capability to serve as an eco-friendly biostimulant for crops under stress(Nazari and Smith, 2023). Furthermore, PGPR-based biofertilizers have shown significant effectiveness in reducing the negative effects of severe drought, high salinity and extreme heat on strawberry photosynthesis by increasing CO₂ diffusion rates while minimizing biochemical damage (García-López et al., 2024). *Bacillus zanthoxyli* HS1 and its volatile organic compounds have shown potential in improving systemic tolerance to salt and heat stresses in cabbage and cucumber plants, as evidenced by physiological markers such as promoting seedling growth while plummeting oxidative stress via augmented activity of antioxidant enzymes, as well as callose accumulation to reduce stomatal opening (Barghi and Jung, 2024). Lastly, pretreatment with “*Bacillus siamensis*-H30-3” and “*B. aryabhatai*-H26-2”provided Chinese cabbage seedlings a higher tolerance to high temperatures. Nevertheless, only *B. siamensis* H30-3 displayed antifungal properties against pathogens such as *Alternaria brassicicola* and *Colletotrichum higginsianum*, indicating the diverse roles that PGPR may serve in plant health management (Lee et al., 2018). Furthermore, Table 1 shows the

prolific contribution of both kinds of microbes “rhzospheric” and “endophytic” microorganisms in alleviating the effect ofHS in plants.

Table 1. Role of Microbes in Enhancing Plant Resilience to Heat Stress

Microbial Strain	Type of Microbial Strain	Plant	Effect on Plant	Reference
Bacillus safensis	Rhizobacteria	Triticum aestivum L.	Restoration of chloroplast structure; reduction in ROS production; enhancement in antioxidative response, chlorophyll content, and osmolyte accumulation	Sarkar et al., 2018
Priestia megaterium (SH-19)	Rhizobacteria	Glycine max (Pungsannam ul)	Improvement in seedling characteristics, salicylic acid levels, and antioxidant defense system activity (GSH, SOD, APX, CAT); decrease in abscisic acid levels; upregulation of transcription factors GmbZIP1 and GmNCED3	Shaffique et al., 2024
Pseudomonas putida (“AKMP7”)	Rhizobacteria	Triticum aestivum L.	Enhancement in length of root and shoot,Improvement in dry biomass, reduction in membrane injury; enhancement in SOD, APX, CAT activities; increase in metabolites (amino acids, chlorophyll, proline, proteins, starch, and sugars)	Ali et al., 2011
Bacillus licheniformis (SSA 61)	Rhizobacteria	Brassica juncea (Mustard)	An augmentation in antioxidant enzyme activities (like “APX”, “SOD”, and “CAT”); enhancement in seed germination and seedling vigor; improvement in biomass, growth of both shoot and root; reduction in ethylene levels	Kiruthika et al., 2023

Bacillus tequilensis SSB07	Rhizobacteria	Soybean	Reduction in ABA production; improvement in growth parameters (like “shoot length”, “biomass”, and “leaf development”); Increase in photosynthetic pigment; enhancement in endogenous “salicylic acid” and “jasmonic acid”	Kang et al., 2019
Bacillus licheniformis BE-L60	Rhizobacteria	Spinach (Spinacia oleracea L.)	Increase in heat tolerance by enhancing soluble protein, proline, sugar content, and antioxidant enzyme functions; improvement in ion homeostasis and activated heat shock protein gene expression	Li et al., 2023
Bacillus cereus SA1 + Humic acid (HA)	Endophytic bacteria	Tomato	Increase in biomass, chlorophyll fluorescence; enhancement in APX, SOD, and GSH activities	Khan et al., 2020a
Penicillium resedanum LK6	Endophytic Fungus	Capsicum annuum L.	Improvement in number of leaves, biomass, and nutrient content; reduction in leaf damage and electrolyte leakage; enhancement in proline and flavonoid synthesis	Khan et al., 2013
Brevibacterium linens	Endophytic Bacteria	Oryza sativa	Lowering in ethylene emissions; reduction in ROS concentrations; increase in “glutathione S-transferase (GST)” and “small heat shock proteins (HSP16, HSP26)” expression, and minimizing proline accumulation	Choi et al., 2022
Aspergillus niger (SonchL-7)	Endophytic Fungi	Sunflower (Helianthus annuus), Soybean (Glycine max)	Enhancement in plant height, biomass, chlorophyll content; reduction in lipid peroxidation and ROS; elevation of ROS-scavenging enzymes (AAO, CAT, GR, SOD, POD); increase in proline and phenolic content	Ismail et al., 2020

Mycorrhizal Fungi: Partners in Heat Tolerance

HS has a profound negative impact on plant growth and development, resulting in diminished vigor, poor seed germination, stunted growth, reduced biomass production, wilting and scorching of leaves and reproductive structures, leaf drop and senescence, fruit damage and discoloration, decreased yields, cell death, and increased oxidative stress (Mishra et al., 2023). Arbuscular mycorrhizal fungi (AMF) are small filamentous organisms that can spread over considerable distances through branched filaments, simultaneously colonizing plant roots and the surrounding rhizospheric milieu. These fungi protect plants from various environmental stressors such as drought, cold, salinity, heavy metal toxicity, nutritional imbalances, industrial waste, biocide treatments, etc. (Wahab et al., 2023). The rhizosphere is surrounded by spores and hyphae produce by AMF in addition to forming vesicles and arbuscules in plant roots. These fungi form a hyphal network in conjunction with plant roots which significantly increase root access to

larger soil surface by improving soil texture and structure and promote better plant growth (Acevedo et al., 2022). By doing this these AMF also enhance sinking effect and facilitate the transfer of photoassimilates from roots to the above-ground parts of plant. This They can also accelerate degradation of organic soil materials. They could also play a major role in fixing atmospheric CO₂ in host plants (Busso et al., 2022). AMF hyphae play crucial role in improving water retention capacity by maintaining soil structure. The AMF symbiosis with plants alters the rates at which water enters, moves through leaves, thereby affecting tissue hydration and leaf physiology (Pauwels et al., 2023). Further, micorrhizal fungi also enhance transpiration rate and stomatal conductance in plants under HS. The proficient exploration of water by AMF can lead to more pronounced wet and dry cycles in the soil, which has a significant impact on soil aggregation. Further, during water scarcity, this symbiotic relation between plant and AMF allows leaves to sequester more carbon, thereby augmenting carbon input to the soil. This is a vital process to

survive under dry environments (Martínez-García et al., 2017). The filamentous hyphal network inside and outside the roots allows plants to absorb more water and essential nutrients from the soil. In exchange of this plant provide essential nutrients such as vitamins, carbohydrates and amino acids required for growth. Many studies has shown the significance of AMF in controlling water transport, influencing tissue hydration and leaf physiology of host plants (Hazzoumi et al., 2015; Bahadur et al., 2019; Fresno et al., 2023). Moreover, these fungi generate altered water dynamics in mycorrhizal plants as compared to non-mycorrhizal plants (Wahab et al., 2023). According to Duc et al. (2018) interactions between plant and mycorrhizal fungi species such as *Septoglomus deserticola* and *S. constrictum* helped to boost plant growth performance under elevated temperature stress. Furthermore, the AMF colonized plant showed improved development and enhanced resilience to various environmental stresses. Ndeko et al. (2022)

demonstrated that AMF (*R. aggregatus* and *F. mosseae*) enhanced growth and HS tolerance in pearl millet. Out of these two AFM *F. mosseae* exhibited superior mycorrhizal colonization while promoting better physiological responses under HS conditions. Kebert et al. (2022) assessed the physiological and biochemical parameters of one-year-old pedunculate oak seedlings (*Quercus robur* L.) exposed to HS (40 °C/30 °C) with ectomycorrhizal (ECM) inoculation. The results showed that mycorrhized seedlings had increased resistance to HS compared to non-mycorrhized controls, as evidenced by higher levels of proline, total phenolics and polyamines. Table 2 shows the vital role of some mycorrhizal fungi in alleviating heat-induced stress in plants and highlights how inoculation with these fungi outcomes in improvements in plant growth, photosynthetic performance, and stress-related physiological responses that are necessary for plant survival at elevated temperatures.

Table 2. Role of Mycorrhizal Fungi in Enhancing Plant Tolerance to Heat Stress

Mycorrhizal inoculants	Plants	Effect on plants	References
Diversispora versiformis	Cucumber	-Enhanced plant growth, chlorophyll levels, and osmolyte (sucrose, fructose, glucose, betaine, proline) accumulation - Upregulated CsPIP1;6 and CsHsp70-8 gene expression.	Liu et al., 2023
Mixture of AM fungi ("Rhizophagus irregularis-BEG140", "R. irregularis", "Funneliformis mosseae-BEG95", "F. geosporum", and "Claroideoglomus claroideum")	Triticum aestivum L. cv. 1110	-Enhanced grain number, modified nutrient allocation, and changes in tiller nutrient composition - Greater carbon availability in spikes	Cabral et al., 2016
Glomus fasciculatum	Cyclamen persicum Mill.	- Reduced leaf browning - Increased antioxidative enzyme activity (SOD, APX) - Elevated ascorbic acid and polyphenol content - Enhanced biomass and growth	Maya and Matsubara, 2013
AMF culture (comprised of "Rhizophagus intraradices", "Funneliformis mosseae" and "F. geosporum")	Maize (Zea mays)	- Improved photosynthesis efficiency (higher PSII quantum efficiency, net photosynthesis rate) - Increased chlorophyll content - Enhanced morphological parameters (plant height, leaf width, cob number) - Better growth due to larger root systems and increased Mg uptake - Protected PSII reaction centers and enhanced primary photochemistry	Mathur et al., 2018

Funneliformis mosseae	Lettuce (Lactuca sativa L.)	- Enhanced chlorophyll content (a & b), net photosynthesis, and transpiration rate under heat stress (35°C) - Improved chloroplast ultrastructure, preventing damage - Better photosystem II (PSII) functionality (reduced heat damage) - Increased energy flux and photosynthetic efficiency	Yan et al., 2021
AM fungus + melatonin	Perennial ryegrass (Lolium perenne L.)	- Improved turf quality, chlorophyll content, net photosynthesis, and leaf photochemical efficiency - Decreased levels of membrane lipid peroxidation and reduced expression of “chlorophyll catabolic genes (CCGs)”, along with “senescence-associated genes” - Elevated water content and reduced electrolyte leakage, H₂O₂, and MDA levels	Wei et al., 2023
Septoglomus constrictum	Tomato (Solanum lycopersicum)	- Lower H₂O₂ and MDA accumulation led to the reduction in oxidative stress - Upregulated stress-related genes (peroxidases, GST, UCH) in both roots and leaves - Upregulated genes related to heat-shock proteins, transporters, and phytohormone metabolism (jasmonic acid, auxin transport, ethylene biosynthesis)	Szentpéteri et al., 2024
AMF inoculum (“Rhizophagus irregularis”, “Funneliformis mosseae”, and “F. geosporum”)	Soybean (Glycine max)	- Enhanced growth (“stem height”, “root length”, “leaf area”, “dry biomass”) - Improvement in chlorophyll level, stomatal density, and the rate of photosynthesis - Better water use efficiency - Increased seed yield and related characteristics - Reduction in canopy temperature	Jumrani et al., 2022

Conclusion

HS, as compelling abiotic stress, represents a growing challenge in the context of climate change, and is significantly affecting global agriculture as crop yield declines. However, plants cope with abiotic stress by exhibiting natural physiological, biochemical, and molecular mechanisms. However, under extreme and long-term conditions, these defenses are often inadequate. There are various tactics that can be used to improve tolerance to severe stress, but the use of biostimulants such as heat-resistant microbial inoculants has emerged as an effective and alternative green approach. These include beneficial microorganisms such as rhizospheric microbes, endophytes and mycorrhizal fungi. When used as bioinoculating agents, their multiple benefits extend beyond stress tolerance to include improved plant growth, making these microbe-mediated strategies more ecologically sustainable compared to traditional chemical or genetic methods. To maximize the potential of these microorganisms, it is important to understand the complex molecular mechanisms underlying plant-microbe interactions across a range of crops and environmental conditions. As an ecofriendly approach, we can advance sustainable agricultural practices and strengthen food security in an increasingly warming world by using HS-tolerant microbes as potential bioinoculants.

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OCCUPATIONAL HEALTH, SAFETY, AND ENVIRONMENTAL MANAGEMENT IN ENGINEERING AND CONSTRUCTION INDUSTRIES

Abul Efham

M. Tech (Health, Safety & Environment) Student– Final Year
Shri Rawatpura Sarkar University (SRU), Raipur, Chhattisgarh, India

***Corresponding Author Email-**aefham@yahoo.com

Abstract

Occupational health, safety, and environmental (OHSE) management is critical in India's construction and engineering sectors due to high fatality rates, regulatory challenges, and underutilization of modern safety technologies. This study evaluates existing OHSE practices, compares them with global benchmarks like ISO 45001 and OSHA standards, and suggests strategic improvements. Through case studies from Tata Steel, L&T, and others, it highlights how AI, training, and structured audits significantly reduce incidents and improve compliance.

Introduction

India's rapid industrial growth has placed enormous strain on safety infrastructure. Despite the Factories Act and OSH Code, incident rates remain high. This article identifies core issues in Indian OHSE systems, such as inconsistent enforcement, limited training, and insufficient adoption of global standards.

Literature Review

Research shows countries that integrate predictive technologies and regular audits (like Japan and Germany) perform better in occupational safety metrics. Indian industries lag behind due to fragmented regulatory execution and low investment in training. ISO 45001 and OSHA serve as performance benchmarks for global safety improvement.

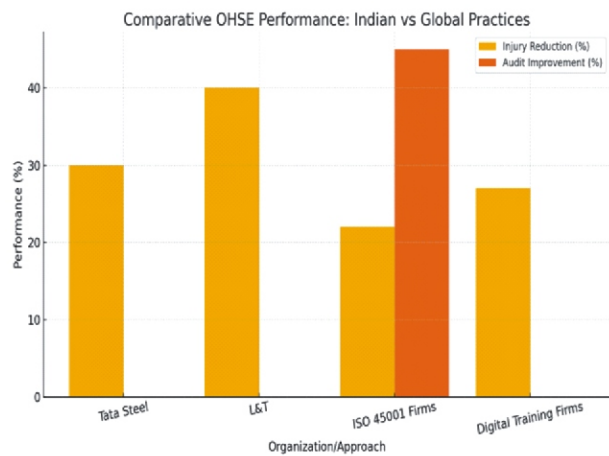
Methodology

This qualitative study used literature review, legal framework analysis, and secondary data from annual reports of Tata Steel, L&T, and other Indian firms. Comparative indicators and descriptive statistics supported insights into accident frequency, audit performance, and safety culture impacts.

Results

- Tata Steel reported a 30% drop in injuries after AI-based safety monitoring.
- L&T recorded a 40% rise in PPE compliance using wearables.
- Firms using ISO 45001 reduced lost-time injuries by 22% and improved audit results by 45%
- Safety training contributed to a 27% reduction in near-miss incidents.

Figure: 1- Comparative analysis of OHSE improvements based on Industry Case Studies



Note:

- 1. Injury reduction (%) achieved by Tata Steel, L&T, and firms with digital safety training.
- 2. Audit improvement (%) seen by ISO 45001-certified organizations

Figure: 2- Global OHSE Benchmark Comparison

A comparison of India's workplace safety performance with global leaders in OHSE practices demonstrates the scope for improvement.

Name of The Country	LTI Rate/100,000 Workers	% ISO 45001 Adoption	Fatalities/Year (Construction)
India	25.4	15%	~12,000
Germany	6.1	78%	~780
Japan	4.2	82%	~610
USA	3.1	70%	~1,008

Data Sources: ILO, OSHA, India MoLE, ISO adoption reports (2020-2023)

"Table 1: Case-Based OHSE Performance"

Organization	Technology / Strategy	Measured Outcome
Tata Steel	AI-based Safety Surveillance	30% reduction in injuries
L&T Infrastructure	Smart Wearables (PPE)	40% increase in PPE usage
ISO 45001 Certified	Standardized Audits	45% audit improvement, 22% LTI drop
Training Providers	E-learning Safety Modules	27% fewer near-miss reports

Discussion

Adopting real-time monitoring systems and

wearable PPE drastically reduced our incident rates and improved audit performance. Safety today needs to be smart, not just procedural.”

— Safety Operations Head, Tata Steel (2021 Sustainability Report)

The findings highlight the benefits of integrating technology into OHSE systems. Key barriers include lack of awareness, cost constraints, and non-standardized training programs. Policy incentives and central safety funding could support SME adoption of smarter safety tools. Comparison with OSHA and ILO standards reveals gaps in India’s implementation of structured safety systems.

Conclusion

To meet international safety standards, Indian industries must invest in digital risk monitoring, enforce regulatory reforms, and ensure workforce safety awareness. Integrating ISO 45001, structured inspections, and AI-driven monitoring can drastically improve India’s OHSE performance. This summary serves to inform practitioners, policymakers, and academic research on future OHSE strategies.

Glossary of Key Terms

- **OHSE:** Occupational Health, Safety, and Environment
- **PPE:** Personal Protective Equipment
- **LTI:** Lost Time Injury
- **ISO 45001:** Global standard for occupational health and safety management systems
- **SME:** Small and Medium Enterprise
- **ILO:** International Labour Organization
- **OSH Code:** India’s Occupational Safety, Health and Working Conditions Code (2020)

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“In safety, there are no compromises — only commitments”

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HEALTH, SAFETY AND ENVIRONMENT IN CONSTRUCTION

Shaik Chand Basha

4th Semester, M Tech-Health, Safety and Environment, Shri Rawatpura Sarkar University, Raipur

***Corresponding Author Email-**@yahoo.com

Abstract

The construction industry in Bengaluru has witnessed rapid growth, but this expansion has raised concerns about Health, Safety, and Environment (HSE) compliance. This study assesses HSE practices in selected construction projects across Bengaluru, identifying key risks, compliance gaps, and best practices. Data was collected through site inspections, worker interviews, and safety audits. Findings reveal inadequate personal protective equipment (PPE) usage, poor waste management, and insufficient safety training. Recommendations include stricter enforcement of safety regulations, enhanced worker training programs, and sustainable waste disposal methods to improve HSE standards in Bengaluru's construction sector.

Keywords: Health, Safety, Environment, Sustainable development, Sustainable waste disposal. Safety of the construction workforce, Environmental compliances, Environment Impact Assessment.

Introduction

India's construction sector is the second-largest employer after agriculture and is expected to grow to USD 1.4 trillion by 2025. Despite this growth, the industry is plagued by poor safety records, limited environmental regulations, and lack of health protections. Workers face dangers such as falls, electrocution, and exposure to dust and chemicals. Moreover, construction activities contribute significantly to urban pollution and waste. This research examines HSE implementation on Indian construction sites and suggests improvements aligned with global best practices.

Literature Review

Studies have shown that:

- According to the National Safety Council (India), over 20% of fatal workplace accidents occur in construction.
- The Building and Other Construction Workers (Regulation of Employment and Conditions of Service) Act, 1996 mandates safety measures, but enforcement is inconsistent.

- Environmental impact assessments (EIAs) are often either bypassed or poorly executed in urban projects.

Methodology

A qualitative and quantitative mixed-method approach was used:

- **Surveys and Interviews:** Conducted with 50 workers, 10 site engineers, and 3 HSE managers from Construction sites in Bengaluru.
- **Observational Analysis:** Focused on PPE usage, waste disposal, air quality, and hazard signage.
- **Policy Review:** Assessed alignment with BOCW Act, ISO 45001, and environmental regulations.

Results and Discussion

Health and Safety Observations

- **PPE Compliance:** Only 55% of workers wore helmets; fewer than 30% used gloves or masks.
- **Training:** Just 35% had undergone any form

of safety induction.

- **Accidents:** Common incidents included falls from scaffolding, cuts from machinery, and eye injuries due to debris.

Environmental Management Findings

- **Air Quality:** High PM2.5 levels observed, especially during demolition and concrete mixing.
- **Waste Handling:** None of the sites had structured waste segregation practices; most waste was dumped unregulated.
- **Noise Pollution:** Measured levels exceeded CPCB limits during peak hours.

Key Challenges

- **Lack of Awareness:** Especially among migrant labourers who make up over 60% of the workforce.
- **Budget Constraints:** Developers reluctant to allocate funds for comprehensive HSE plans.
- **Regulatory Enforcement:** Inspections are irregular and often superficial.

Recommendations

1. Mandatory HSE Training

- Regular safety workshops in regional languages.
- Certification systems for skilled labor.

2. Technological Integration

- Use of smart PPE, IoT-based site monitoring for gas leaks, dust levels, and noise.

3. Enforcement of Regulations

- Strengthen the role of state labor inspectors.
- Digitize reporting under the BOCW Act.

4. Environmental Best Practices

- Encourage on-site dust suppression methods.
- Set up temporary waste sorting stations.

5. Worker Welfare Measures

- Provide healthcare support, insurance, and

clean sanitation facilities.

Conclusion

The construction industry in India must treat HSE not as a compliance burden but as a strategic priority. This study highlights the urgent need for systemic reforms, including enhanced training, investment in safety equipment, and enforcement of environmental norms. Addressing HSE gaps will not only save lives but also improve project efficiency and public trust in the construction sector.

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GREENHOUSE GAS EMISSION CALCULATION AND REDUCTION STRATEGY FOR AUTOMOBILE INDUSTRIES

Zain Lardi

M Tech-Health, Safety and Environment, SRU University, Raipur

***Corresponding Author Email-**zainlardi@yahoo.com

Abstract

Introduction

Greenhouse gas (GHG) emission calculation and reduction strategies are vital for environmental sustainability in the automobile manufacturing industry. Major GHG sources in this sector include diesel generators, PNG/LNG gas, in-house vehicle fuel usage, electricity consumption, boilers, and furnaces.

This report examines GHG emissions at a major automobile parts manufacturer in India (confidential under NDA) and outlines potential strategies for reduction based on globally accepted calculation methods.

Importance of GHG Reduction

Once the GHG emissions are calculated, the next step is the reduction strategy. Normally, the GHG reduction strategies are engineering methods through which either energy consumption or fuel consumption is reduced. Sometimes the strategy can be administrative too GHG reduction strategies contribute to:

- Limiting global warming (<2°C as per Paris Agreement)
- Improving energy efficiency and operational costs
- Enhancing brand reputation and regulatory compliance
- Supporting Sustainable Development Goals (SDGs)

Quantifying GHG emissions allows organizations to identify key sources and target

mitigation strategies, contributing directly to climate goals and sustainable operations.

Methodology

The report follows **IPCC** and **DEFRA** protocols for emission quantification.

IPCC Approach:

- Emissions = Activity Data × Emission Factor
- Emission factors derived from IPCC guidelines based on fuel type
- Tiers of calculation:
 - Tier 1: Default factors
 - Tier 2: Country-specific factors
 - Tier 3: Facility-level data

DEFRA Approach:

- Uses specific emission factors available from UK's DEFRA conversion tables.
- Applied especially for electricity, transport, and refrigerants.

GHG Inventory and Emission Sources

An inventory was created to document fuel and electricity usage. Key data categories include:

Scope 1 (Direct Emissions):

- Diesel/petrol use (generators, company vehicles)
- CNG/LPG usage
- Refrigerant leaks (R22, R32, SF6)

Scope 2 (Indirect Emissions):

- Purchased electricity (grid + renewable)
- Purchased heating/cooling

The calculation included emission factors for all relevant fuels and electricity sources, using IPCC and DEFRA standards.

Results and Discussion

Emission Profile

Scope 1 and Scope 2 emissions were dominant. Emissions were highest from:

- Diesel generators
- Grid electricity
- Furnaces and boilers

Refrigerant leaks and captive power plant emissions were also significant.

Reduction Measures Implemented

- Replacing 2HP with 1HP pumps
- Switching 400W sodium lamps to 100W LEDs
- Converting diesel DG sets to PNG
- Installing solar panels
- Optimizing compressor usage
- Enhancing power factor (from 0.88 to 0.95)
- Encouraging public transport for employees
- Introducing energy management systems and audits

Expected Outcomes

Environmental

- Lower Scope 1 and 2 emissions
- Cleaner air quality
- Reduced fossil fuel dependence

Economic

- Energy savings
- Lower carbon-related penalties

- Competitive advantage in sustainable markets

Strategic

- Improved public and investor trust
- Strengthened stakeholder engagement
- Enhanced resilience against climate risks

Future Scope

- **Real-time Emission Monitoring** using IoT sensors and AI
- **Expansion to Scope 3:** supplier and product lifecycle emissions
- **Digital GHG Accounting** with blockchain-enabled traceability
- **AI-Powered Predictive Modeling** for emissions
- **Policy Development** support and cross-industry collaboration
- **Employee Upskilling** in carbon management practices

Conclusion

This report showcases a practical GHG emission assessment using internationally accepted methodologies. By identifying high-emission sources and implementing actionable strategies, significant environmental and operational benefits can be achieved. Future efforts must focus on technology integration, policy alignment, and industry-wide standardization to meet India's net-zero target by 2070.

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HEALTH, SAFETY AND ENVIRONMENTAL IMPACTS OF MINING

Vikash Kumar

M. Tech in Health, Safety & Environment Engineering, SRU University, Raipur

***Corresponding Author Email-**@yahoo.com

Abstract

The mineral industries and Mining activities, in general, cause extensive environmental damage. Dealing with them is in many cases technically possible, but the cost is often prohibitive in an industry.

Two of the most important tools for controlling environmental accidents are the Environmental Impact Assessment (EIA), which is a statutory requirement, and the voluntary tool Environmental Management System (EMS). Despite EIA being demanded by law in most countries there are no general definitions of the processes or the report. Identification of techniques and, more particularly, clear and unequivocal evidence regarding environmental impacts at all stages of production are becoming quite relevant. An attempt has been made in this paper to identify various aspects needed to improve environmental standard of the surroundings.

Thus, Environmental impact assessment and approvals management are fundamental for minimising risk and maximising outcomes.

Introduction

Mining projects unavoidably result in big interference in the environment and significant source of pollution problems. The most serious consequence is that tailings and acid drainage often contain toxic heavy metals and/or sulphides, which easily can be transported to aquatic systems and cause great damages to the ecosystems. There have been a number of reported environmental accidents in relation to mining and mineral processing industry, from all over the world. These environmental accidents and their consequences are quite serious in nature in degrading environmental standard and general ecology. Mines, irrespective of, whether they are operational or closed, affect environment. Mining does not seem to agree with the concept of sustainable development. Mining, however, is a traditional industry and many nations' growth, development, employment, income etc., depend on mining and mineral industry. It is therefore most certain that mining will continue to be an important industry in the future, regardless of its

environmental impact.

Now, the public have become more aware of the environmental risks associated to mining. The pressure on the mining industry to find a sustainable solution is now growing tremendously everywhere, specially in developed world.

The environmental legislation applicable for mining companies is not uniform everywhere. The global environmental problems have only been in focus since last almost 30 years and before that environmental legislation was virtually non-existent. As a result from the United Nations' various world summits on the environment, combined with alarming reports from researchers on the bad environmental state on Earth, the environmental legislation is now developing rapidly and is being imposed.

Two of the most important tools for the environmental work are the Environmental Impact Assessment (EIA), which is a statutory requirement, and the voluntary tool Environmental Management System (EMS).

Objectives of EIA And EMS

Environmental Impact Assessments (EIA) is in general required for mining projects in most of the countries. In developed countries voluntary work methods are also playing an increasing role in the environmental protection efforts. To help organisations take control over their environmental impacts, **Environmental Management Systems (EMS)** have been developed.

Organisations can choose to adopt a standardized system, such as the Eco Management and Audit Scheme (EMAS) which is an International Standard ISO 14001. Some companies create their own system, and some use branch specific EMS guidelines, like the Code for Environmental Management which is developed for mining companies by the Minerals Council of Australia.

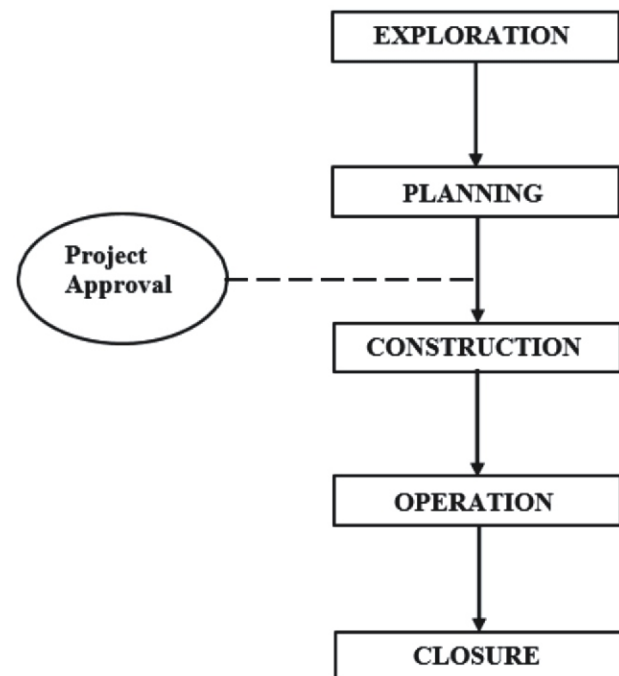
Since its introduction in 1996, the ISO 14001 International Standard, which specifies requirements for Environmental Management Systems (EMS), has been adopted by National Standards bodies in more than 130 countries. ISO 14001 is viewed by many governments, businesses, and non government organizations (NGO) as one of the best hopes for attaining worldwide sustainable development and continual improvement in environmental management and environmental performance through self-regulation and self-monitoring. Because of its global reach, ISO 14001 is becoming a passport to international trade, as companies registered to the Standard can claim to have demonstrated to independent registrars that they have implemented basic management principles and practices which integrate environmental considerations into business decision-making and operational controls.

The level of ambition of the EMS is usually closely connected to the existing environmental legislation in the country, since the law is a minimum level for the environmental performance in an organisation. The EMS is a tool for a company to secure the statutory requirements first and to constantly raise the level of standard by taking further actions in the environmental field than those demanded by the law.

For regulators and certified EMS consultants, it is necessary to investigate and study how best EIA and EMS can be used in the mining and related industry with the purpose of reducing the environmental effects and long-term costs for society, connected to the restoring of old mine areas. The aim of such study should be to illustrate the problems with the mine management regarding present environmental issues, and to educate potential of the future efforts. By suggesting a way of using EIA and EMS as helpful tools the intention is to encourage the mining sector's ambition to create a safe and environmentally sustainable mining.

The Mine Project Life

Typical mining projects consist of five main phases; exploration, planning, construction, operation and closure.



When an area possibly suitable for mining is found, the exploration begins with sampling, mapping and surveying. After collecting basic data the planning of the project can start. The planning stage includes choice of mining method and processing of the ore, design and engineering of the site etc. When authorities have approved the project and issued the required permits the construction and thereafter the operational stage takes over. Construction includes constructing

shafts and tunnels or removing overlying rock, and in the operation phase ore is extracted and processed. Finally the closure may include clean-up, sealing wastes and shafts and make the area available for other users.

Possible Environmental Impacts from Mining

The environmental impacts from mining range from changes in the landform to the release of pollutants to the air, water and soil of the surroundings. The extent of the environmental impact depends on what minerals are being extracted, and naturally of the properties of the mine such as size and methods. With effective environmental management many of the impacts can be reduced, and some of them even eliminated, but it is impossible to operate a mine without causing any environmental disturbances. Below are some examples of potential environmental impacts from a mining project.

- a. **Landscape and physical destruction** - First of all, the excavations cause alterations to the landscape. The most common type of mine is the open pit mine, which is a surface excavation. The rock overlying the ore body is removed and taken away from the pit, in order to reach the underlying ore body.

The other type of mining, underground mining, takes place when the minerals lie deeper beneath the surface. Underground mining can cause subsidence in the land above the mine.

Both open pit and underground mines result in extensive interference on the physical landscape, which can lead to for example changes in landform, alteration of the water table, land instability with increased erosion, and flow modifications in nearby rivers. Both types of mines produce waste that occupy large amounts of land and degrade earth surface extensively. An open pit mine yields more waste per tonne of ore, and makes a larger interference in the landscape, compared to an underground mine. An underground mine may lead to the same types of impacts on the landscape in other aspects. Except for the mine site itself the waste disposals, including the dams, and connecting roads also occupy land. The waste is disposed either on land or under water in large dams. In either case the waste is often deposited close to the mine site, for economical reasons.

As a consequence of the alterations in the physical environment, the ecosystems are affected. Natural environments for flora and fauna may diminish or even disappear at the mine site and waste disposal site. The river ecology may be changed due to sedimentation and flow modification.

When constructing the mine and during its operational stage, groundwater is pumped up in order to reach lower parts of the ore body. Water may also be taken up for use in the mines and processing of minerals. The consumption of water leads to a reduction of the groundwater table, which can have a severe impact on the aquifers and surface vegetations.

- b. **Pollution** - The mine waste constitutes rock, which is extracted in order to reach the ore. Tailings include rock and remainders of the ore that can not be extracted in the processing. Both wastes and tailings from mines contain ore and other minerals, including heavy metals and/or sulphides. When the material is brought up from the subsoil and put into contact with the air, it oxidizes, and the pH decreases. In contrast to particles the dissolved ions are bio-available, i.e. they can be taken up by plants and animals, and accumulate in the food chain. If put in touch with infiltrating water, or in case of a dam breakage accident, the heavy metals and acids is easily transported to the surroundings.

Water from ore processing plant, as well as pumped out groundwater from the mine also contains fine particles of the ore. Apart, it may contain heavy metals and sulphides. These are transported by water streams and sediments may be deposited to form new beaches in the estuaries and deltas. In addition, the refining processes sometimes contain chemicals such as cyanide and sulphuric acids, which is mixed and spread with the surface water.

Explosives that are used in mines contain nitrate, which becomes mixed with the waste rock, tailings and processing water. The nitrate contributes to forced eutrophication, which may lead to the land that surrounding watercourses become overgrown. The refining operations usually conduct different air emissions. The characteristics of the emissions are naturally dependent on the type of ore is being extracted. Further, the excavation process may lead to dust emissions.

There is also a risk of oil and fuel spill from the working vehicles.

- c. **Energy consumption** – Mining and mineral industry as a whole is very energy consuming. Movement and processing of large volumes of material requires great amounts of energy. It is estimated that mines and smelters take up a tenth of all energy used each year globally. The energy consumption causes large discharges of carbon dioxide, which contribute to one of the most important global environmental problems, the greenhouse effect.
- d. **Health impacts** - Environmentally harmful substances and processes are harmful to humans. For instance the exposure to dust and fugitive emissions as well as the handling of toxic chemicals can negatively affect the health of the mining employees. Working at the mine site could include risk of physical injuries as well, due to the heavy vehicles and even collapses in the mine. Vehicles, fans, blasting etc., may cause disturbing noise and vibrations.

Moreover, people who live close to the mine might have to suffer from the dust, noise and vibrations as well as from polluted water and air. The mine can also reduce the aesthetic values of an area, which may be difficult to restore to its former state even after closure of mines.

United Nation's Environmental Initiatives

Before the 1970s global environmental problems were given very little attention. There were very few laws on environmental protection and environmental problems were considered as local or regional problems. As public awareness regarding environmental issues are increasing throughout the world, the need for global environmental solutions has become even more important. Thus, United Nation has come into the picture to address various issues on global environmental front. As per UN initiative, a number of summits on the environmental issues have brought the world's leaders together to discuss the global environmental problems. The results of such meetings are to a large extent to bring general awareness among various countries and to keep uniformity in making environmental legislations globally.

- a. **Stockholm Conference** - In 1972 the United Nations Conference on the Human Environment was held in Stockholm, Sweden. Representatives from 113 countries met to "consider the need for a common outlook and for common principles to inspire and guide the peoples of the world in the

preservation and enhancement of the human environment". This was the first time the relationship between economic development and environmental degradation was given attention. After the conference, the United Nations Environment Programme (UNEP) was set up, to act as 'the world's environmental conscience'.

- b. **Brundtland Report** - In 1983 the World Commission on Environment and Development was created by the UN. Lead by G. Brundtland, the Commission presented a report named "Our Common Future" in 1987. The Brundtland Report supported the need for economic development, which should, however, be sustainable. In the report sustainable development was defined as: "*development which meets the needs of the present without compromising the ability of future generations to meet their own needs*". The concept of sustainable development has been central to the environmental debate since then, and the challenge is now to make that objective reality.
- c. **Rio Earth Summit 1992** - The United Nations Conference on Environment and Development (UNCED), also known as the Earth Summit, was held in Rio de Janeiro, Brazil, in 1992. The Conference resulted in a number of important agreements. The Rio Declaration on Environment and Development contains a number of principles defining the rights and responsibilities for States. It was in this Declaration that the "precautionary approach" and "polluters pay principle" were first discussed.
The comprehensive action plan Agenda 21 is an international environmental programme for sustainable development with the message "think globally, act locally". In addition the United Nations Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity, and the Statement of Forest Principles were signed at the UNCED.
- d. **Johannesburg Summit 2002** - The World Summit, the United Nations Conference on Sustainable Development, was held in Johannesburg in August-September 2002. Representatives from 190 countries met to discuss sustainable development issues and to follow up the outcomes of the UNCED. They also agreed on further action to implement Agenda 21. An important question was how to reduce the poverty in some parts of the world while creating a sustainable development. Commitments were made to increase access to clean water and proper sanitation, to increase access to energy services, to improve health conditions and agriculture,

particularly in drylands, and to better protect the world's biodiversity and ecosystems

Some form of Environmental Impact Assessment (EIA), and accompanying procedures for information disclosure, public participation and judicial or administrative review, have become widely adopted as part of the project and/or policy review process in most countries.

In 1969 the US government introduced EIAs as an “action-forcing mechanism” to identify, assess, and mitigate environmental and human impacts of government actions in the United States. Since then, EIAs have spread to well over 100 countries, and have been enshrined in Principle 17 of the Rio Declaration, gaining worldwide legitimacy as a critical element of environmental management. EIAs have grown in both strength and scope and are now one of the premiere tools in environmental management in most countries. EIAs should address some of the basic factors listed below:

- Meteorology and air quality. Ambient levels of pollutants such as sulphur dioxide (SO₂), oxides of nitrogen, carbon monoxide (CO), suspended particulate matters, should be determined. Additional contribution of pollutants at the locations are required to be predicted after taking into account the emission rates of the pollutants from the stacks of the proposed plant, under different meteorological conditions prevailing in the area.
- Hydrology and water quality
- Site and its surroundings
- Occupational safety and health
- Details of the treatment and disposal of effluents (liquid, air and solid) and the methods of alternative uses.
- Transportation of raw material and details of material and details of material handling.
- Impact on sensitive targets.
- Control equipment and measures proposed to be adopted including post-mining reclamation.

Preparation of environmental management plan is required for formulation, implementation and monitoring and of environmental protection measures during and after commissioning of projects. Planning for closure and reclamation

should begin during the earliest stages of project development, before operations start at a new site, and continues throughout the mine life. Goal is to minimize the disturbance of land in all phases of the mine life and to provide a post-closure land use which is compatible with traditional uses or provides sustainable advantages to the local communities.

Instruments for Environmental Protective Measures

Two frequently used tools to help companies and organisations take the environmental situation under control are EIA and EMS. EIA is an instrument in the process of issuing environmental permits for new activities. It is carried out before the activity has begun and aims to predict the environmental impact from an activity in order to prevent unexpected environmental impacts from occurring in the future.

EMS is a voluntary tool for companies to help follow up their environmental performance and to secure that the environmental objectives are reached. The most important factor that rules the environmental work is nevertheless the environmental legislation. The law determines the requirements of the EIA and the legislation is also important for the design of EMS, since the general commitment of an EMS is to consider the legislation as a minimum requirement and at the basis of that work for continual improvements. An EMS is in its turn an excellent way of controlling the environmental performance of the activity and secure compliance with the law. It is in other words of importance to investigate both voluntary tools and legal requirements, and identify the potential synergy between them, in order to create an efficient environmental work.

a. Environmental Impact Assessment (EIA) -

There are many purposes of the EIA, but above all it is an aid in giving the environment a natural part in the planning and decision-making of a project. the assessment should be a framework for considering location, design and environmental issues. It is considered that if all aspects of the project are taken into consideration from the beginning the planning process will be smoother. Effective EIA is an aid in the decision-making, where it simply should initiate better decisions being taken. Better decisions in this case could be

defined as the decisions that contribute to:

- an approach to sustainable development,
- protection of human and animal health and
- minimised environmental damage

The UN Economic Commission for Europe has stated that, "The purpose of EIA is to give the environment its due place in the decision making process by clearly evaluating the environmental consequences of a proposed activity before action is taken. The concept has ramifications in the long run for almost all development activity because sustainable development depends on protecting the natural resources which is the foundation for further development."

The contents of the assessment, as well as how the process for obtaining a permit should proceed, are more or less regulated in the legislation in different countries. All environmental impacts that might be a result of the planned activity, directly and indirectly, should be identified. Sometimes social and cultural impacts are included too, since they often are closely connected to the environmental impacts. Usually alternative suggestions shall be made regarding location, design and work methods of the activity, including their possible impacts. Though it is important to perform the assessment thoroughly to achieve a satisfying result, it is never possible to assess all impacts in detail. The environmental consequences must always be weighed against the economical aspects. Therefore it is important to be efficient and to know what is demanded in an EIA, to be able to achieve a constructive result.

In fact, an EIA makes it possible to identify all major effects to follow from the planned activity, before the damage is done. EIA generally makes the planning process more transparent and open to the public, since the plans for the project together with the assessment of the environmental impacts must be presented to and discussed with the general public and others concerned.

- b. Environmental Management System (EMS)** - EMS is a voluntary tool that helps organisations identify their environmental situation and by formulating environmental objectives strive for reduced environmental impact. The EMS can also be considered as a tool for meeting the environmental policy. An EMS should include the following parts:

- an evaluation of all activities within the company which may result in any form of environmental impacts

- development of procedures for controlling the environmental impacts, (for example environmental objectives, education of employees, environmental monitoring and environmental audits)
- interaction between all parts, and
- procedures for corrective actions.

The company can choose either to create its own EMS, or to adopt a standardised system. Besides, not all companies have the ambition to fulfill all requirements of an EMS standard. Especially for smaller companies the costs for a certification process is considerable, and some companies therefore choose to build up a system according to a standard, but refrain from the certification. The advantage with a standardised EMS is that the audits can be carried out in a systematic way, by an independent auditor, which increases the confidence from the public. A certified system is the only way to show customers and others that all requirements of the standard are fulfilled in a correct way.

By using an EMS a company can reduce its environmental impact through a commitment to continual improvement. When identifying which activities constitute environmental problems the company can make developments such as reducing the amount of waste and improving the recycling, and thus cut down on the cost for raw material and energy. The benefits of an EMS might therefore include both a better environmental performance as well as economical profits for the company. Reducing the negative impacts on the physical environment may also result in a better working environment, as there are less chemicals and harmful substances in use.

Goals, in general, should be accomplished Through Permit Process

- Reviewing permit, revision, field amendments applications for completeness and technical adequacy.
- Ensuring that adequate bond to complete reclamation is posted by the permittee.
- Conducting complete and partial inspections on coal permits as required by state and federal rules and regulations and the specific requirements of the approved permit such that non-compliance items are identified and

appropriate abatement measures implemented.

- Conducting annual and mid-term permit reviews in compliance with statutes and regulations.
- Conducting bond release inspections in compliance with statutes and regulations.
- Conducting citizen complaint inspections in compliance with statutes and regulations.
- Gathering evidence and testifying at hearings as required by statutes and regulations.
- Conducting Student Outreach Programs at local area schools to provide students and teachers with a better understanding of the mining process.
- Receiving on-going training and information concerning current technical advances and trends in mining, safety, and reclamation.

Strategic Environmental Assessment (SEA)

One of the most recently developed tools for environmental management is Strategic Environmental Assessment (SEA). SEA is a way of carrying out the EIA at a more strategic level of development – at policies, plans and programmes. SEA can be defined as “the formalised, systematic and comprehensive process of evaluating the environmental impacts of a policy plan or programme and its alternatives, including the preparation of a written report on the findings of that evaluation, and using the findings in publicly accountable decision-making”.

SEA has been developed as a result of the shortages of the current EIA system on project level. It is estimated that, the use of SEA is likely to grow in the future and also improve the process of project EIA. The concept of SEA can be termed as a first step of the process of integrating EIA with EMS. That is because if a SEA is carried out in a large area, an EIA for a new project would only need to contain the project specific facts, if it is carried out within the framework of the SEA.

Suggestions for Effective Environmental Work in the Mining Industry

As described above EIA and EMS are two tools for identifying and controlling the environmental impact from an activity. The two concepts are

distinguished in several ways. The most significant difference is that EIA is a legal requirement whereas the EMS is voluntary. In addition the EIA is carried out before a project is started, to identify possible environmental impacts from the planned project. It constitutes the basic data for the environmental authorities' decision-making in the case. EMS, on the other hand, secures a systematic and controlled way of working in order to fulfill the environmental targets and contribute to continual improvements while the activity is in operation. In EMS the legislation is the minimum requirement.

Nevertheless, the concepts are connected. Both methods focus on identifying what parts of the activity cause environmental impacts, estimating the nature of the impacts and finding methods to reduce them. Used together the tools can efficiently improve the results of the environmental work. The EIA should not be seen as an instrument for the environmental authorities' decision-making only; it is also an important tool for planning the design and methods of the activity. If considering the EIA as a part of the initial step of the EMS the characteristics of the two methods can collaborate in a useful way. The first steps of the planning process of an EMS could then be completed early in the project, to assist the information in the EIA when the decision whether to issue an environmental permit is taken by the environmental authorities.

An important property of the EMS is that the method is created to be a voluntary tool, and it should not become a legal requirement in the future. It is however possible to encourage companies to introduce EMS.

As mentioned, the SEA system is possibly the next step in the ambition to create sustainable development but, as far as the author knows, it needs extensive development before the method can be applied.

To each phase of the mine project one or several phases in the environmental work can be connected. Following fundamental requirements are to be looked into:

- a. **Organisational commitment** - Environmental work is not something that goes on in one environmental department only at a company.

Environmental issues and measures shall be integrated in all activities in a company to achieve an efficient result. The environmental plans and follow-up should be included in the overarching operational planning. In order to make the environmental efforts possible to carry out, and to obtain a well-functioning EMS, all employees must be committed to the aim of the EMS.

As stated in ISO 14001 the management is responsible for providing resources, including human and financial resources as well as technology, essential to the implementation, maintenance and control of the EMS. One of their most important tasks is to inspire and encourage all employees to take out the environmental actions. In order to make everyone committed to the EMS, all employees must understand why the actions are taken out. Therefore environmental training should be given to everyone.

b. Environmental legislation and authorities -

A well-functioning legislation in the environmental field has proved to be of great importance to motivate companies to improvements

c. Preparation of environmental work at exploration stage -

During the exploration phase a larger area of interest is investigated by, for example, studying of geological maps, performing of overarching geotechnical surveys and geochemical monitoring. The purpose of these investigations is to get a picture of the conditions of the area, and to select a smaller area for further investigations and planning of a mine site. In this phase some preparations for the EIA can be carried out. Concerning the environmental work the exploration phase should include preparations for the carrying out of the EIA, such as putting an EIA-EMS team together and creating an exchange of knowledge and information with the environmental authorities, the general public and other stakeholders.

d. Consultations with public - A major project will always affect many parties. To be able to communicate with all stakeholders from an early stage, the principal actors should be identified. Example of the ones who may be affected or interested by the planning and development of a project are, except for the developer: (i) Other companies affected by the project, for example companies in the same group, neighbours, competitors or others having economical interest in the development, (ii) Financers and insurance companies, (iii) Private individuals affected directly or indirectly by the project, (iv) General

public, (v) Authorities, (vi) NGO with special interests, (vii) Mass media, (viii) Future customers.

e. Planning - In the planning phase further geological and geotechnical conditions should be investigated in order to plan the mine project. The design and methods of the activity are chosen. In addition the environmental characteristics should be investigated and included in the conclusions and the planning.

The EIA should be started at an early stage of the project to prevent environmental matters from being thought of after the design and methods are decided and difficult to change. The EIA-EMS should therefore be fully integrated with the planning of design and methods.

In this phase the support from the environmental authorities is of decisive importance. The authorities should assist in the identification of what data is necessary to investigate and give advice for the assessment as well as the contents and design of the EIS. It should also be secured that all legal requirements on the EIA are observed.

f. Performance of the assessment - Before the start of the assessment the EIA-EMS team should agree on how the assessment is to be carried out, to make the different elements in accordance with each other. The time schedule should be settled, to make it possible to benefit from each other's results and to prevent unnecessary delay. The performance should be arranged to ensure that the necessary data is collected and documentations such as map scales, lay-out in the report, etc., are uniform.

g. Identification of legal and other requirements -

The minimum level for all efforts of the project is set up by the legal requirements. All environmental legislation that applies to the activity must be identified and documented to ensure that the activity is within the legal framework. The authorities should help defining the responsibilities of the developer. Specific environmental rules, like threshold values for the activity, are usually not possible to establish at an early stage, unless a SEA is accomplished. Other requirements on the activity, apart from the law, may include demands from owners, customers and/or suppliers.

h. Monitoring of background data - Securing background data before the project is started helps getting a picture of the present situation. The monitoring can be carried out in parallel to the other investigations of the area. Parameters such

as waterflow, hydrology and erosion potential should be identified as well as existing aquatic and terrestrial habitats. These parameters should be an input to decisions regarding design and performance. For example, the presence of threatened, endangered or rare species may change the conditions for the approval of the mine, as well as physical parameters that will make a possible discharge of contaminants difficult to prevent.

Environmental conditions, such as the occurrence of pollution in the area, should also be analysed in order to make it possible to identify changes in conditions during active mining. When investigating the condition of the area before any activity is started the monitoring should include the quality of water, sediments and air (concentrations of elements and compounds as well as amount of particles in air). The background data should, as well as the measurements of the operating mine, give particular attention to the concentrations of bioavailable elements and compounds. Since the bioavailable compounds are taken up by living organisms they constitute the most harmful part of pollution. It should also be considered what parameters may change due to an activity. The concentrations of certain elements and compounds that are likely to be released from the future activity should be monitored in the first place, in order to detect a possible increase when the activity has started.

Monitoring is generally expensive to carry out, hence it should be carefully planned which data to prioritised.

i. **Predicting the impacts – environmental review** - The main purpose and the core of the EIA are to identify what impacts the planned activity will cause, and to suggest measures to minimise the negative environmental impacts. With some additional information this makes the EIA suitable as an environmental review to base the EMS on. The environmental impacts of mining activity can be divided into following types:

- **First and higher orders impact.** Impact of first order is the impact that follow directly from the activity, for example a decrease in pH in surrounding waters caused by leakage of acid mine drainage. Second order impact includes the consequences of the first order impact, for example extinction of sensitive species. Accordingly, third order impact consists of the consequences of the second order impact, for example further ecosystem
- changes in the watercourses. The higher order the impacts are, the more difficult they are to assess.
- **Direct and indirect impact.** Direct impact is caused by the mine itself, for example pollution of watercourses. Side-effects of the mine activity, for example a decrease of tourism in the area, are described as indirect impact.
- **Cumulative impact.** The cumulative impact is the total impact from many activities in the area. The synergetic effect may lead to heavy pollution, despite each activity only releasing a small amount of pollutants.
- **Significant and insignificant impact.** In order to make the scope of the EIA manageable the significant impact must be identified. The selection should be done carefully though as it is often hard to estimate what impact will be significant. For the same reason it might be unsuitable to use the term “insignificant” at all.
- Impact which is **regulated by the law** is relatively easy to identify. It is important however not to forget about the consequences that are not regulated by law. The legislation should be seen as minimum requirements only.
- Besides the environmental impact, **social, economic and cultural impact** is often included in the EIA as well, since they are difficult to separate, and they affect each other.
- **Positive and negative impact.** It is often forgotten that there might be a positive impact as well as a negative resulting from the proposed project.
- **Short-run and long-run impact.** An example of a short-run impact is the impact that lasts as long as the activity is in operation and then disappears again, whereas the long-run impact can be visible long after the closure.
- **Local and strategic impact.** Some environmental impact is local only, whereas in other cases the impact includes larger areas and cause regional, national or even international and global impact.

- **Reversible and irreversible.** Environmental resources cannot always be replaced. The irreversible impact is not possible to mitigate, and activities causing irreversible damage should be considered with caution.
- **Quantitative and qualitative impact.** Some environmental impact is measurable and can be described in quantitative terms. Other causes a decrease in quality instead, and their extent may be more difficult to estimate.
- **Distribution by group and/or area.** The impact is not evenly distributed on affected parties and areas. Even if an activity brings a general benefit, the negative impacts might affect one group and/or area, and the benefits some other.
- **Actual and perceived impact.** Usually only objective predictions of impacts are considered. But the subjective perceptions of impacts may influence the public and decision-makers even more.
- **Relative to other developments.** Alternatives must always be considered.

Since it at first might be difficult to identify the environmental impacts of a project, and to value the importance of each effect, one idea is to start with a 'brainstorming', where no selection is made at all. A list of all potential impacts creates a starting point, from which it is possible to plan what areas will be included in the assessment. It might be necessary to get help from experts to distinguish the important and less important impacts from the project, and concentrate on the major ones. Opinions obtained from the consultation with the public should naturally be included in the assessment.

Besides the main environmental impacts of a project, the EMS usually focuses on the activities that are causing the significant environmental impact. The aim of the EMS is to control these activities and to improve them, in order to cause less environmental damage. The activities that cause the most important environmental impacts of the company are called the significant environmental aspects. In order to identify these activities, it is favourable to study the whole processes of the activity rather than, for example,

only the end-points where the pollutions are released. The significant environmental aspects are fundamental in the future environmental work. They underlie the formulation of the environmental policy and environmental objectives.

Except for the environmental impacts an environmental review should also include an analysis of the environmental work of suppliers and subcontractors as well as an investigation of the working environment.

For mining projects, the following impacts should be given special attention.

- (i) Environmental and health impacts from extraction and processing of the ore, waste management and usage of final products made from the ore.
 - (ii) Consumption of natural resources
 - (iii) Environmental impacts from accidents and incidents
 - (iv) Environmental impacts from contractors and suppliers
- The following impacts should also be considered, bearing in mind the general nature of mining projects.
- (v) Energy consumption
 - (vi) Pollution of air, soil and groundwater

j. Planning for closure - To be able to present an overall picture of the environmental impacts from an activity, the whole project life should be taken into consideration. Mining is one of the few projects that are known to have a limited duration. The legislation should therefore require a plan for the closure from the beginning of the project. It is of economical advance since it is possible to spread the costs over a longer period of time. The closure can be financed by the profitability of the mine and the mining company will then not have to finance the whole cost for the closure at the same time as the cash flow is decreasing. Planning for closure involves investments to reduce the total environmental impacts, such as cleaner technology and/or treating the pollution at the source. This kind of preventive measures could be of interest for the governments, especially in developing countries, since it promises reduced environmental costs at the same time as it maintains the social and economical benefits of mining.

By using an EMS the planning for closure could be more effective, since it means that action plans are developed in order to reduce the time laps between

damage occurrence and remediation. Further the EMS aims to reduce the use of natural resources and the amount of waste generated.

- k. Consideration of alternatives** - It should be a legal requirement that different alternatives for the project are investigated in the EIA, in order to find the best final solution.

Examples of alternatives to consider in a mining project

Site layout	Open pit or underground mine? Will office buildings be situated at the site or somewhere else? Where can the connecting roads be located?
Location	Where can the waste deposit be located? Where can the processing of the ore take place? What routes can be chosen for the transportation?
Operating conditions	What methods can be used to extract the ore? What processing methods can be used? What energy sources can be used?
Processing and Equipment	Which is the best available technology (BAT)?
Ways of minimising environmental impacts	Prevention at source or after-treatment? Different operation techniques?
Management of mine waste and tailings	Waste piles on land or water filled dams?

- l. Consideration of previous experiences** - Some common mistakes in the planning process may be avoided by studying other similar mining projects, and learn from their experiences.

- m. Emergency preparedness and response** - The risk for accidents and emergency situations should be carefully considered. The possible emergency situations should be reported on, together with a description of how the risks are minimised.

An action programme for emergency preparedness and response should be established, based on the identification of risks for accidents and emergency situations. To achieve a programme that works as intended both training of the employees as well as a close collaboration with the rescue service is required.

- o. Environmental policy** - When the significant environmental aspects and legal requirements of a project are determined it is possible to establish an environmental policy for the company. The environmental policy informs the community and the company's own employees about the environmental goals and level of ambition.

- p. Environmental objectives and targets** - Environmental objectives and targets should first and foremost be based on, and be in compliance with, the significant environmental aspects, legal and other requirements and the environmental policy of the project. Other facts, such as technical options, financial requirements and views of interested parties, should also be taken into consideration when establishing the environmental objectives and targets. Determining the objectives at this early stage is of great advance since it makes it possible to choose for example operational methods in view of the environmental objectives, and not the other way around.

- q. Monitoring and measurements** - A programme for monitoring and measurements should be established. The programme should define what parameters to monitor, and how it should be done, in order to check the environmental performance of the activity. The programme should include procedures for the construction and operation phase, as well as the after closure control. The purpose of the monitoring and measurements is to be able to discover unpredicted impacts on the environment, and react to the non-conformances. The monitoring and measurements programme helps the authorities to estimate whether the control of the environmental performance is enough, or if additional actions must be taken.

Discussion and Conclusions

It can be concluded that EIA is a common requirement in the application of environmental permits in many countries today. The overall purpose of the EIA is also fairly the same everywhere; to identify and describe the environmental impacts from a planned project, and suggest methods to minimise it.

Moreover, to suggest a work method perfectly brought into line with the problems in the mining industry today, a study among several mining companies would be essential. The study should aim to identify the specific environmental problems in the mining industry and to better understand the reason why the mining companies are as hesitant to incorporate existing EMS in their companies. Except for the use of EIA and EMS, other tools available for environmental management, such as life cycle assessment, should also be considered.

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IMPACT OF ORGANIC MANURE ON THE GROWTH PARAMETERS OF BROCCOLI (*BRASSICA OLERACEA L. VAR. ITALICA PLENCK*). CV. KTS-1

Sonit Kumar^{1*}, Vijai Kumar², Shobhit Sharma³

¹Ph.D. Scholar, Department of Horticulture, Ch. Chhotu Ram (PG) College, Muzaffarnagar (U.P)

²Professor, Department of Horticulture, Ch. Chhotu Ram (PG) College, Muzaffarnagar (U.P)

³Ph.D. Scholar, Department of Horticulture, Chaudhary Charan Singh University campus Meerut (U.P)

*Corresponding Author Email-shobhitsharma2014@gmail.com

Abstract

The present field experiment titled “Impact of Organic Manure on the Growth, Parameters of Broccoli (*Brassica oleracea* var. *italica* cv. KTS-1)” was conducted during the Rabi seasons of 2021–22 and 2022–23 at the Horticulture Research farm Department of Horticulture of Chaudhary Chhotu Ram (P.G.) College, Muzaffarnagar (U.P.). The study aimed to evaluate the effects of various organic manures and their combinations on broccoli performance. Thirteen treatments combinations were tested, including T₁ Control (Absolute) T₂ (FYM @ 60 t/ha), T₃ (Vermi Compost @ 20 t/ha), T₄ (Poultry Manure @ 20 t/ha), T₅ (FYM 75% + Vermi Compost (25%)), T₆ (FYM 75%+ Poultry Manure (25%)), T₇ Vermi Compost 75% + Poultry Manure (25%), T₈ FYM 50% + Vermi Compost (50%), T₉ FYM 50% + Poultry Manure (50%), T₁₀ Vermi Compost (50%) + Poultry Manure (50%), T₁₁ FYM (25%) + Vermi Compost (75%), T₁₂ FYM (25%) + Poultry Manure (75%) and T₁₃ Vermi Compost (25%) + Poultry Manure (75%). Result of the study revealed that plant height was highest in T₁₃, averaging 50.73 cm across two growing seasons, compared to 30.35 cm in the control. Similarly, T₁₃ achieved superior leaf number, dimensions, stalk and root lengths, dry and fresh weights, with a remarkable curd yield of 141.79 q/ha versus 131.09 q/ha in the control. These findings underscore the potential of combining vermicompost and poultry manure to improve crop productivity and nutritional quality, while promoting sustainable agricultural practices. Future studies should investigate the long-term impacts of organic amendments on soil health and their adaptability across diverse cropping systems.

Keywords: broccoli, organic manure, Vermicompost, poultry manure, FYM

Introduction

Broccoli is often referred to as the “crown of jewel nutrition” due to its abundance of vitamins and minerals. It surpasses cabbage with an impressive 130 times more vitamin A content. One of its key components is sulforaphane, which exhibits tumor cell growth inhibition properties and lowers the risk of cancer. In a 100-gram serving, broccoli contains approximately 89.3% water, 3.6% protein, 0.2% fat, 5.5% carbohydrates, 1.2% fiber, 900 I.U. of Vitamin A, 137 I.U. of Vitamin C, 1.29 mg of calcium, 1.3 mg of iron, 0.79 mg of phosphorus, and 1.26 mg of sulfur (Meena

et al., 2017). Broccoli, especially broccoli seed sprouts, is abundant in antioxidant sulforaphanes, known for their anti-carcinogenic properties. These compounds not only protect against cancer but also shield the eyes from UV light damage and aid in preventing high blood pressure, heart disease, and stroke. Moreover, broccoli is a good source of carotene and ascorbic acid, further adding to its nutritional value.

In India, broccoli cultivation covers approximately 4 lakh hectares, resulting in an annual production of 85 lakh metric tonnes (National Horticulture Board, 2021).

Worldwide, the broccoli cultivation area spans about 13 lakh hectares, producing approximately 25 million metric tonnes annually. In India, the significant broccoli-producing states include Himachal Pradesh, Uttarakhand, Uttar Pradesh, Bihar, Maharashtra, and Karnataka, among others. In Uttar Pradesh, commercial cultivation of broccoli takes place in districts such as Saharanpur, Kanpur, Raibareli, and Unnao, among others.

The organic vegetable industry is experiencing rapid growth, fueled by concerns over pesticide residues in food and the environment, leading to a surge in demand for organic produce. The utilization of organic nutrient sources has proven to be an effective approach for reducing production costs and maintaining soil fertility over extended periods. Crops cultivated with organic fertilizers exhibit superior environmental and nutritional qualities compared to those relying on chemical fertilizers (Tiwari *et al.*, 2021). With each passing day, the trend of choosing organically grown vegetables is on the rise, as people become more health-conscious. Simultaneously, the incorporation of organic inputs enhances soil physical and biological properties, elevates water holding capacity, increases cation exchange capacity, and reduces bulk density, fostering the proliferation of beneficial soil microorganisms. The application of organic nutrients in the form of farmyard manure (FYM), poultry manure (PM), and vermicompost (VM) is known to positively influence all soil properties, ultimately leading to improved nutrient uptake from the soil.

Organic agriculture is widely recognized as a favorable method of agricultural production, as it ensures a harmonious balance between human welfare and sustainable development. Organic fertilizers are rich in essential macro and micronutrients, vitamins, and various growth-promoting compounds. As suggested by Hammad *et al.* (2019), incorporating locally produced manures in broccoli cultivation can lead to increased yields while reducing the reliance on chemical fertilizers. These organic fertilizers are abundant in sugars, proteins, amino acids, and humic acids, all of which directly contribute to the overall growth and development of plants. For centuries, the application of farmyard manure

(FYM) to soil has been a common practice, and it has proven to be beneficial for sustainable agriculture. FYM application has resulted in increased crop yield, improved soil properties, enhanced soil fertility, higher soil organic matter content, increased microbial activities, and improved soil structure. This natural fertilizer contains all the necessary macro and micronutrients required for plant growth, with its primary effects attributed to nitrogen, phosphorus, and potassium. Typically, well-decomposed farmyard manure contains nitrogen (0.53%), phosphorus (0.22%), potassium (0.59%), iron (2100 mg Kg⁻¹), zinc (61 mg Kg⁻¹), boron (2.2 mg Kg⁻¹), and molybdenum (0.75 mg Kg⁻¹). The application of FYM has been shown to enhance the growth and yield parameters of crops like mustard. In addition to providing essential macro and micronutrients, FYM also increases the availability of inorganic nutrients from manufactured mineral fertilizers, leading to a positive impact on the number of leaves per plant, thereby augmenting the photosynthetic surface of the leaves.

Vermicompost is a valuable organic manure known for its slow-release properties, providing a steady supply of both macro and micronutrients to plants over an extended period. This nutrient-rich compost plays a significant role in reducing the C:N ratio of the soil, while simultaneously increasing the content of beneficial humic acids. Moreover, vermicompost serves as an accessible source of nutrients for plants, offering readily available forms of nitrate, exchangeable phosphorus, soluble potassium, calcium, and magnesium (Talashilkar *et al.*, 1999). Additionally, vermicompost contains biologically active substances, including plant growth regulators, as reported by Krishnamoorthy and Vajranabhaiah (1986).

Poultry manure plays a vital role as a nutrient-rich source with direct positive effects on plant growth. In addition to providing major nutrients, poultry manure contains traces of essential micronutrients that are often not supplied by commercial fertilizers but are crucial for optimal plant growth. Numerous studies have documented its effectiveness as an excellent organic manure, enhancing nutrient uptake by

plants (Abusaleha, 1992 and Jose *et al.*, 1988). conclusions.

Material and Method

The experiment was conducted on Impact of Organic Manure on the growth parameters of broccoli (*Brassica Oleracea L. Var. Italica Plenck*). cv. KTS-1 during *Rabi* season at Horticulture Research farm Department of Horticulture Chaudhary Chhotu Ram (P.G.) College, Muzaffarnagar (U.P.) India, during the year 2021-22 and 2022-23. The experiment was laid out into Randomized Block Design (RBD) with 3 replications with 13 treatments viz. T₁ Control (Absolute) T₂ (FYM @ 60 t/ha), T₃ (Vermi Compost @ 20 t/ha), T₄ (Poultry Manure @ 15 t/ha), T₅ (FYM 75% + Vermi Compost (25%)), T₆ (FYM 75% + Poultry Manure (25%)), T₇ Vermi Compost 75% + Poultry Manure (25%), T₈ FYM 50% + Vermi Compost (50%), T₉ FYM 50% + Poultry Manure (50%), T₁₀ Vermi Compost (50%) + Poultry Manure (50%), T₁₁ FYM (25%) + Vermi Compost (75%), T₁₂ FYM (25%) + Poultry Manure (75%) and T₁₃ Vermi Compost (25%) + Poultry Manure (75%).

On the basis of soil testing, the soil of the experimental site was medium in available nitrogen, phosphorus and potassium but low in organic carbon. The soil of the experimental field was well-drained, with sandy loam having good moisture and heat-absorbing capacity. Pusa KTS-1 variety of broccoli was selected for the present study. Nursery beds were made in standard size (1 x 2 m) from 15 cm high from ground surface. Weeding, irrigation & plant protection measures were adopted timely to maintain healthy seedling growth. As per treatments, vermicompost, poultry manure and FYM was applied into the soil seven days before the transplanting of seedling on the basis of chemical analysis. 30 days old, healthy, vigor stocky and uniform seedlings of broccoli were transplanted in the experimental field as per the layout plan during third week of October in two successive years i.e., 2021-22 and 2022-23. Standard culture practices recommended for broccoli were followed uniformly in all experimental plots. The data recorded during the course of the investigation were subjected to statistical analysis by the analysis of variance (ANOVA) technique (Fisher, 1958) for drawing

Result and discussion

The results indicated a significant influence of various treatments on plant height, with the maximum height observed in treatment T₁₃ (Vermi Compost (25%) + Poultry Manure (75%)), recording heights of 50.52 cm and 50.93 cm in 2021-22 and 2022-23 respectively. In contrast, the control group showed the minimum height of 30.2 cm and 30.5 cm. This trend was consistent across pooled data, where T₁₃ exhibited a height of 50.73 cm compared to the control's 30.37 cm. The enhanced plant height in T₁₃ can be attributed to the nutrient-rich profile of vermicompost and poultry manure, which improves soil structure, enhances microbial activity, and increases nutrient availability. The synergistic effect of these organic amendments likely promotes better root development and nutrient uptake, leading to greater plant vigor. Similar findings were reported by Bahadur *et al.* (2006) and Maurya *et al.* (2008).

The maximum number of leaves was recorded in T₁₃ (20.92 and 23.02) followed by T₁₂ (20.71 and 22.82) and T₁₀ (20.61 and 22.72). The control group exhibited the minimum leaf counts (16.27 and 18.32). The pooled data supported these findings, with T₁₃ showing an average of 21.97 leaves compared to 17.29 in the control. The increase in leaf number in treatments containing organic amendments can be linked to enhanced nutrient availability and improved soil health, which promote photosynthetic activity and overall plant growth. Similar findings were reported by Dalal *et al.* (2010), Choudhary *et al.* (2012)

Leaf length measurements also mirrored the trends observed in height and leaf number, with T₁₃ recording the maximum leaf lengths (20.71 cm and 22.65 cm) and control exhibiting the shortest lengths (16.1 cm and 16.0 cm). The pooled data showed T₁₃ at 21.47 cm versus the control's 17.07 cm. Longer leaves in T₁₃ may result from improved nutrient uptake and optimal moisture retention associated with organic amendments, facilitating better photosynthetic efficiency. Similar findings were reported by Kumar *et al.* (2010).

Similar to the previous parameters, leaf width was greatest in T₁₃ (14.94 cm and 17.02 cm) and

lowest in control (11.02 cm and 13.12 cm). The pooled analysis indicated a maximum of 15.96 cm for T₁₃ and a minimum of 12.06 cm for control. Wider leaves may enhance light interception and improve photosynthesis, which can contribute to increased biomass production. Similar findings were reported by **Meena et al. (2017)**

Stalk length followed the same trend with T₁₃ showing the highest values (8.81 cm and 9.78 cm) and control showing the lowest (6.14 cm and 7.09 cm). Pooled data confirmed T₁₃ at 9.30 cm and control at 6.62 cm. Enhanced stalk length in T₁₃ can be attributed to better nutrient absorption, leading to stronger structural support for the plant. Similar findings were reported by **Hammad et al. (2019) Singh et al. (2021)**

Stalk length followed the same trend with T₁₃ showing the highest values (8.81 cm and 9.78 cm) and control showing the lowest (6.14 cm and 7.09 cm). Pooled data confirmed T₁₃ at 9.30 cm and control at 6.62 cm. Enhanced stalk length in T₁₃ can be attributed to better nutrient absorption, leading to stronger structural support for the plant. Similar findings were reported by **Hammad et al. (2019) Singh et al. (2021)**

Dry weight was highest in T₁₃ (14.90 gm and 16.36 gm) and lowest in control (11.1 gm and 12.56 gm), supporting the trend observed in earlier metrics. The pooled analysis indicated T₁₃ at 15.63 gm and control at 11.83 gm. Higher dry weight in T₁₃ likely results from improved overall plant health and increased nutrient uptake due to the combination of vermicompost and poultry manure. These results are accordance with **Sakhonwasee S. (2015), Singh et al. (2021)**

Fresh weight mirrored dry weight findings, with T₁₃ showing maximum values (200.6 gm and 206.50 gm) compared to control (150.60 gm and 150.50 gm). The increased fresh weight in T₁₃ can be attributed to the enhanced growth parameters facilitated by organic amendments, resulting in more substantial biomass accumulation. Similar findings were reported by **Wani et al. (2010)**

The highest curd yield was observed in T₁₃ (140.80 and 142.78 q/ha), while control yielded significantly less (130.1 and 132.08 q/ha). Pooled data also indicated T₁₃ yielded 141.79 q compared to control's 131.09 q. The cumulative benefits of organic amendments result in enhanced growth, development, and ultimately yield, reflecting the treatment's effectiveness in optimizing crop performance. Similar findings are related with **Chaterjee et al. (2005)**.

Table 1: Effect of organic manure on the growth parameters of broccoli (*Brassica Oleracea L. Var. Italica Plenck*). cv. KTS-1

Not	Treatments	Plant height (cm)		Number of leaves		Leaf Length (cm)		Leaf Width (cm)		Stalk length (cm)	
		2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
T ₁	Control (Absolute)	30.20	30.53	16.27	18.32	16.43	17.75	11.02	13.12	6.14	7.09
T ₂	FYM @ 60 t/ha	30.30	31.84	17.01	19.12	16.14	17.45	11.13	13.22	7.17	8.03
T ₃	Vermi Compost @ 20 t/ha	32.51	33.26	17.23	19.32	16.54	17.85	11.27	13.32	7.29	8.19
T ₄	Poultry Manure @ 20 t/ha	30.62	31.36	17.45	19.52	17.69	18.95	12.38	14.42	7.48	8.39
T ₅	FYM (75%) + Vermi Compost (25%)	33.83	34.42	17.65	19.72	17.74	19.05	12.59	14.62	7.62	8.51
T ₆	FYM (75%) + Poultry Manure (25%)	36.06	37.01	19.14	21.22	17.06	18.35	12.08	14.12	7.04	7.99
T ₇	Vermi Compost (75%) + Poultry Manure (25%)	39.67	40.58	19.42	21.52	18.53	19.85	13.66	15.72	6.53	7.49

T₈	FYM (50%) + Vermi Compost (50%)	42.46	44.44	19.22	21.32	18.44	19.75	13.54	15.62	6.22	7.19
T₉	FYM (50%) + Poultry Manure (50%)	43.74	44.72	19.73	21.82	18.63	19.95	13.04	15.12	6.73	7.69
T₁₀	Vermi Compost (50%) + Poultry Manure (50%)	47.07	48.04	20.61	22.72	19.52	20.85	14.70	16.82	8.40	9.39
T₁₁	FYM (25%) + Vermi Compost (75%)	45.52	48.68	20.02	22.12	19.01	20.35	14.03	16.12	8.09	8.94
T₁₂	FYM (25%) + Poultry Manure (75%)	48.68	50.17	20.71	22.82	19.82	21.15	14.86	16.92	8.62	9.59
T₁₃	Vermi Compost (25%) + Poultry Manure (75%)	50.52	50.93	20.92	23.02	20.71	22.65	14.94	17.02	8.81	9.78
	C.V	5.72	6.75	0.80	2.23	0.66	0.65	0.49	0.73	0.34	7.09
	C.D	7.42	9.31	0.27	0.76	0.22	0.22	0.17	0.25	0.11	0.09

Table 2: Effect of organic manure on the growth parameters of broccoli (*Brassica Oleracea L. Var. Italica Plenck*). cv. KTS-1

Not.	Treatments	Root length (cm)		Dry weight of plant (gm),		Fresh weight of plant (gm),		Curd Yield (q/ha)	
		2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
T₁	Control (Absolute)	40.2	40.64	11.1	12.56	150.6	156.50	130.1	132.08
T₂	FYM @ 60 t/ha	40.5	40.94	11.5	12.96	150.9	156.80	130.2	132.18
T₃	Vermi Compost @ 20 t/ha	60.0	60.44	11.2	12.66	160.0	165.90	132.2	134.18
T₄	Poultry Manure @ 20 t/ha	60.3	60.74	12.0	13.46	160.3	166.20	132.5	134.48
T₅	FYM (75%) + Vermi Compost (25%)	60.6	61.04	12.8	14.26	180.1	186.00	133.4	135.38
T₆	FYM (75%) + Poultry Manure (25%)	50.0	50.44	12.5	13.96	180.4	186.30	134.9	136.88
T₇	Vermi Compost (75%) + Poultry Manure (25%)	50.4	50.84	13.9	15.36	170.3	176.20	135.2	137.18
T₈	FYM (50%) + Vermi Compost (50%)	50.2	50.64	13.7	15.16	170.2	176.10	136.6	138.58
T₉	FYM (50%) + Poultry Manure (50%)	50.8	51.24	13.4	14.86	170.5	176.40	137.4	139.38
T₁₀	Vermi Compost (50%) + Poultry Manure (50%)	70.2	70.64	13.8	15.26	200.2	206.10	138.5	140.48
T₁₁	FYM (25%) + Vermi Compost (75%)	70.0	70.44	14.5	15.96	200.0	205.90	139.3	141.28
T₁₂	FYM (25%) + Poultry Manure (75%)	70.4	70.84	14.2	15.66	200.6	206.50	140.7	142.68
T₁₃	Vermi Compost (25%) + Poultry Manure (75%)	70.6	71.04	14.9	16.36	200.4	206.30	140.8	142.78
	C.V	2.31	2.39	0.69	0.63	7.86	6.39	4.97	6.97
	C.D	0.78	0.81	0.23	0.21	2.67	2.17	1.69	2.37

Conclusion

The present study demonstrated that the impact of organic manures, particularly the combination of vermicompost and poultry manure, significantly enhanced the growth and yield parameters of broccoli compared to individual applications and the control. Among all treatments, T13 consistently outperformed others, indicating the synergistic benefits of combining organic amendments. These results underscore the importance of adopting organic manure for sustainable and environmentally friendly crop production.

Hence, soil application of Vermicompost 25% + poultry manure 75% (T₁₃) may be suggested in case of broccoli (cv. KTS-1) in order to obtain higher vegetative growth and curd yield under Western Uttar Pradesh conditions.

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EFFECT OF IRRIGATION SCHEDULING AND FERTILITY MANAGEMENT ON PROTEIN CONTENT (%), NUTRIENT CONTENT & ECONOMICS PARAMETERS OF BASMATI RICE

Sanskriti Singh¹, Vikash Tyagi¹ and Hariom Katiyar²

¹Department of Agronomy, Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut (U.P.), 250110, India.

²Department of Vegetable Science, Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut (U.P.), 250110, India.

***Corresponding Author Email-**atgmail.com

Abstract

A field experiment was conducted during *kharif* season 2022 at Crop Research Centre of Sardar Vallabhbhai Patel University of Agriculture & Technology Meerut (U.P.) India to study the “Effect of varied irrigation scheduling with level and times of nitrogen application on crop water productivity of wet rice (*Oryza sativa* L.)”. The soil of the experimental field was well-drained, sandy loam in texture, and slightly alkaline. It was low in organic carbon and available nitrogen but medium in phosphorus and potassium. The treatments were; five irrigation scheduling *viz.* (I₁) IW/CPE 0.8 throughout the growth stage, (I₂) IW/CPE 0.8 upto panicle initiation stage & thereafter IW/CPE 1.0 upto dough stage, (I₃) IW/CPE 0.8 upto panicle stage and thereafter 1.2 upto dough stage, (I₄) IW/CPE 1.0 throughout growth stage, (I₅) IW/CPE 1.0 upto panicle initiation stage & thereafter IW/CPE 1.2 upto dough stage and six fertilizer management i.e. (N₁) 100% RDN : 4 equal splits at 15, 30, 45 & 60 DAT, (N₂) 100% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT, (N₃) 125% RDN : 4 equal splits at 15, 30, 45 & 60 DAT, (N₄) 125% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT, (N₅) 150% RDN : 4 equal splits at 15, 30, 45 & 60 DAT, (N₆) 150% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT was laid out in split plot design with three replications.

Results of the experimental field were revealed that growth parameters *viz.*, plant height, number of tillers, dry matter accumulation, LAI and yield attributes *i.e.* panicle length, number of panicles, number of grains panicle⁻¹, and 1000-grains weight were significantly maximum in treatment (I₅) followed by (I₃) and (I₄). The grains, straw, and biological yield (47.32; 68.54 and 115.86 q ha⁻¹) and harvest index (40.84%) were found higher under treatment (I₅). The maximum water use efficiency (2.77 q ha⁻¹ cm) and water productivity (2.12 kg cm⁻³) were recorded in (I₅). (I₅) also recorded highest available NPK (222.7, 15.2 and 184.6 kg ha⁻¹). Treatment (I₅) had 30.3% cost of cultivation over conventional tillage (I₁). The maximum gross return was recorded into the treatment (I₅) followed by (I₃) and (I₄).

Among fertilizer management, treatment (N₆) recorded tallest plants (99.4 cm) with highest number of tillers m⁻² (248.5 m⁻²) and dry matter accumulation (1343.1 g m⁻²), along with the yield attributes *i.e.* number of panicles, number of grains panicle⁻¹, 1000- grains weight and grain yield were significantly higher in fertilizer management (N₆). Among different fertilizer management maximum net return (Rs.96099) was found in nutrient management practice (N₆) which is found at par with (N₄) (Rs.93237). However, benefit cost ratio was found to be highest (2.41) with (N₆) which was closely related with (N₄) *i.e.* (2.40) and lowest with (N₁) (2.33).

To achieve highest grain and straw yield of rice with higher profit, application of (I₅) IW/CPE 1.0 upto panicle initiation stage & thereafter IW/CPE 1.2 upto dough stage and (N₆) 150% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT are better option.

Keywords- protein content (%), Nutrient content, economics Parameters, Basmati rice.

Introduction

“Rice (*Oryza sativa* L.) is important staple food crop consumed by majority (more than 60%) of world’s population, providing approximately 20% of total energy intake for humans. It is a high caloric food, which contain 75% starch, 6-7% protein, 2-2.5% fat, 0.8% cellulose and 5-9% ash. So, it is used as staple food crop and eaten as cooked rice and also used for various preparation and has commercial and industrial importance. Beside grains, its straw and rice hulls are used as fodder, mulching, packing and as insulation materials etc. It plays a vital role in national food security for millions of rural households. Rice is the substantial part of protein intake for millions of people living in poverty in Asia. Asia’s food security depends mainly on irrigated low land rice fields, which produces three-quarters of all rice harvested. In Worldwide, rice is cultivated over an area of about 164.19 million hectares with production and productivity 513.02 million metric tons and 31.24qha-1, respectively” (Anonymous, 2021). “India occupies a pride place in rice production among the food crops cultivation in the world. Area of rice in India increased 1.5 times, productivity 3 times (2752 kg ha-1) and production > 4 times (124.37 million tonnes). West Bengal is the highest producing state and other leading states are Uttar Pradesh, Punjab and Chhattisgarh. In Uttar Pradesh, rice is grown on 5.95 million hectares area with production of 15.52 million tonnes and productivity of 26.34 qha-1” (Anonymous, 2021). “Irrigation scheduling is the decision of when and how much water to apply to a field. Its purpose is to maximize irrigation efficiencies by applying the exact amount of water needed to replenish the soil moisture to the desired level. Irrigation scheduling saves water and energy. The scarcity of water for agriculture production is becoming a major problem in many countries, particularly in world’s leading rice producing countries like China and India. Rice cultivation in India is predominantly practiced under transplanting method that involves raising, uprooting and transplanting of seedlings. This

technique requires continuous ponding of water” [1,2]. “The fertilizer N recovery efficiency has been found to be around 30-40% in rice with the current practices. Nitrogen nutrition due to the considerable impact on growth parameters and physiological traits of rice is important. The percentage of light penetration, photosynthesis active radiation, light use efficiency, dry matter partitioning to different parts are affected by the amount of nitrogen. Nitrogen is typically the nutrient that most often limits rice yields and hence the nutrient needed in largest quantity among the fertilizer. Appropriate doses of N fertilizer and establishment method is important to increase nitrogen use efficiency in rice” (Ranjan and Yadav, 2019). “Nitrogenous fertilizers are one of the most important fertilizers that influence rice yields. It promotes tillers development; yield attributes and increases yield. The rice crop produced maximum grain yield in response to nitrogen application in three splits. Scheduling of irrigation in rice plays a major role in obtaining higher yields as well as higher water productivity” (Keerthi, et al., 2018). Water management is one of the major factors responsible for achieving better harvest in crop production. Efficient irrigation through timely supply of water in desirable amount and with proper irrigation method not only improves the crop yields but also improve water use efficiency. Phogat et al. (2009) reported that “the growth yield attributes and yield of rice increased significantly with the increase in number of irrigations. Applications of three irrigations significantly increased grain yield by 15.5% & 52.8% over two and one irrigations, respectively. Adequate supply of moisture in soil helps in proper utilization of plant nutrients, resulting in proper growth and high yield. Irrigation and fertilizer management are important agronomic practices for higher yield. Irrigation influence favor the growth and yield attributes of rice by supplementing the water need of the crop. It also enhances availability of different nutrients to crop plants”. In a field investigation carried out by [3] with rice crop, they

reported that “irrigation applied at flowering and grain filling stages significantly increased grain yield of rice over that of pre-flowering and grain filling stages”. Bharti and Prasad (2002) found that “grain yield of rice increased significantly up to an IW/CPE ratio of 0.8 with irrigations, such of 5cm depth. Irrigation thus, plays a vital role in increasing the growth and yield of rice. So, in researches, water use efficiency measured is very important”. Tomer et al. (1992) showed that “consumptive use of water was increased significantly up to two irrigations applied at pre-flowering and fruiting stages but water use efficiency was increased only up to one irrigation applied at flowering stage in rice”. Yadav et al. (1999) reported that “consumptive use of water increased by increasing levels, whereas water use efficiency decreased with irrigation”.

Materials and Methods

A field experiment was conducted at Crop Research Center (CRC) of Sardar Vallabhbhai Patel university of Agriculture & Technology, Meerut, Uttar Pradesh during the kharif season (2022). The details of the experimental materials used and the methods adopted during the course of investigation are described briefly in this chapter.

Experimental Site and Location

The experiment was conducted at Crop Research Centre (CRC), Chidori of Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut situated in Indo-Gangetic Plains of Western Uttar Pradesh in Western Plain Zone. The CRC is geographically located at 29° 08' 12" N latitude, 77° 40' 52" E longitudes and at an elevation 232 meters above the sea level.

Soil Moisture Constants of the Experimental Soil

The soil moisture retention capacities at saturation, field capacity and permanent wilting point and bulk density of the soil prior to conducting the experiment were estimated from 0-15 and 15-30 cm soil depths by following procedures of Dastane et al. (1967) and the estimated data are presented in Table 1.

Table 1. Moisture retention characteristics of the experimental soil

Soil depth (cm)	Moisture per cent at				Available soil moisture (mm)
	Saturation (0 bar)	Field capacity (0.2 bar)	Permanent wilting point (15 bar)	Bulk density (g cm ⁻³)	
0-15	26.2	24.6	14.1	1.32	20.79
15-30	25.8	23.0	13.6	1.35	18.83

Weather and Climate

The data on climatic parameters such as rainfall (mm), mean maximum and minimum temperature, evaporation, air velocity and relative humidity recorded at meteorological observatory, Sardar Vallabhbhai Patel University of Agriculture & Technology Meerut, (U.P.) for the year 2022 was used in the present study. The climate of this region is characterized as semi-arid and sub-tropical. The summer is very hot and dry while winters are too cold. Moderate rainfall and wide temperature variation is the characteristic features of the semi-arid and sub-tropical climate. Generally, South- West monsoon sets in the third or fourth week of June, reaches its peaks in July and August, and continues up to September, cyclonic weather leads to few winter rains. The area receives mean annual rainfall of 845 mm, of which 80-90 per cent is received from June to September. Winter season extends from November to February, whereas frost occurs generally in the end of December and may continue up to the end of January. The mean minimum temperature reaches as low as 3°C in winters, while during summer the mean maximum temperature varies from 43-45°C in the month of May. The meteorological data showed that average maximum and minimum weekly temperature varied from 40.3 and 38.50C to 15.9 and 16.10C during the crop period in the year 2022, respectively. However, the mean maximum and minimum relative humidity varied from 95.8 and 88.1 to 46.8 and 41.7% during the crop period in the year 2022, respectively. Though, the total rainfall 587.6 mm was received during year of investigation, respectively.

Varietal Description

Pusa Basmati 1637 is a semi-dwarf Basmati rice variety with sturdy stem and plant height

ranging from 95 - 100 cm. Therefore, it does not lodge. It takes 115-120 days for seed-to-seed maturity, the shortest duration for any Basmati rice variety released so far. This variety has given yield in the range of 4.2 to 6.5 tons/ha in large scale demonstrations conducted in the Basmati growing regions of Punjab, Haryana, Delhi and Uttar Pradesh. The variety was developed by the Division of Genetics, Indian Research Institute, New Delhi.

2.5 Design and Layout of the Experiment – The experiment was laid out in a split plot design with two irrigations scheduling as first factor treatments and second factor treatments has six fertilizer management of rice are replicated thrice. The experimental field was provided with main irrigation channels and sub- Irrigation channels as shown in layout plan and the individual plots were demarcated by bunds. The layout plan of the experiment is depicted Table 2.

Table 2. The experiment was conducted as per the plan given below

S. No.	Particulars	
1.	Design	Split Plot Design
2.	No. of treatments	combination Main plot: 5 Sub-plots: 6
3.	No. of replications	3
4.	Total plots	90
5.	Gross plot size	10 m x 3.0 m = 30 m ²
6.	Net plot size	8 m x 2.5 m = 20 m ²
7.	Variety Pusa Basmati	1637
8.	Spacing	25 x 10 cm 20 x 10 cm
9.	Irrigation channel	Main irrigation – 2m Sub –irrigation -1m
10.	Season Kharif	2022

Table 3. Treatment details

Treatments Used		Symbols
Irrigation Scheduling (First factor):		
T1	IW/CPE 0.8 throughout the growth stage	I ₁
T2	IW/CPE 0.8 up to panicle initiation stage & thereafter IW/CPE 1.0 up to dough stage	I ₂
T3	IW/CPE 0.8 up to panicle stage and thereafter 1.2 up to dough stage	I ₃
T4	IW/CPE 1.0 throughout growth stage	I ₄
T5	IW/CPE 1.0 up to panicle initiation stage and thereafter IW/CPE 1.2 up to dough stage	I ₅

Fertilizer Management (Second- factor):		
T1	100% RDN: 4 equal splits at 15, 30, 45 & 60 DAT	N ₁
T2	100% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT	N ₂
T3	125% RDN: 4 equal splits at 15, 30, 45 & 60 DAT	N ₃
T4	125% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT	N ₄
T5	150% RDN: 4 equal splits at 15, 30, 45 & 60 DAT	N ₅
T6	150% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT	N ₆

Available nitrogen (Subbaiah and Asija, 1956)

Available nitrogen was estimated by alkaline KMnO₄ method where the organic matter in soil has oxidized with hot alkaline KMnO₄ solution. The ammonia evolved during oxidation was distilled and trapped in boric acid and mixed indicator solution. The amount of NH₃ trapped was estimated by titrating with standard acid (Subbaiah and Asija, 1956).

1. Transfer 20 g of soil in a distillation flask. Add 20 ml water and 100 ml of 0.32per cent KMnO₄ solution.
2. Take 20 ml of 0.02 N H₂SO₄ in a 250 ml conical flask and add two or three drops of methyl red indicator. Put the flask below the receiver tube. Keep the tip of the receiver tube well dipped into the H₂SO₄ solution.
3. Add 100 ml 0.32% KMnO₄ and 100 ml of 2.5% NaOH to the distillation flask containing soil and immediately connect the flask with the distillation apparatus.
4. Start heating the distillation flask. The free ammonia thus released was absorbed in the H₂SO₄ solution. Continue the distillation till the evolution of ammonia from distillation flask takes place; test it by bringing a moist red litmus paper near the outlet of condenser, which will turn blue as long as ammonia is being evolved. No change in red litmus paper shows the completion of the ammonia distillation.
5. Titrate the excess of H₂SO₄ with 0.5N NaOH and note the volume.

Formula:

$$\text{Available N in soil (kg/ha)} = \frac{(S - B)}{20} \times 10^6 \times 2.24$$

Where,

S- Sample value

B- Blank value

Available phosphorus (Olsen et al., 1954)

Available phosphorus was extracted with sodium bicarbonate (0.5 M) at 8.5 pH and the amount of phosphorus in the extract was estimated by chlorostannous reduced phosphomolybdate blue color method using spectrophotometer at wave length of 660 nm. It was expressed in kg ha^{-1} .

1. Take 5 g of soil into a 250 ml conical flask and add a little amount of activated charcoal.
2. Add 100 ml of 0.5 M NaHCO_3 solution into the flask and shake the conical flask for 30 minutes on a mechanical shaker.
3. Filter the suspension through a Whatman No. 1 filter paper and take 5 ml aliquot of the extract in a 25 ml volumetric flask.
4. Add 5 ml of ammonium molybdate solution and a little quantity of distilled water and shake the contents of the volumetric flask.
5. Add 1 ml of working SnCl_2 solution in each 25 ml volumetric flask and make the volume upto 25 ml with distilled water and shake well.
6. Measure the transmittance of the solution preferably within 5 to 20 minutes after the addition of SnCl_2 solution on 660 nm in a spectrophotometer.
7. Simultaneously run a blank without soil following the same procedure and take the reading.

Available potassium (Jackson, 1973)

The 1 N ammonium acetate was used to determine the available potassium in soil.

1. Take 5g of processed soil in a 150 ml conical flask.
2. Add 25 ml 1 N ammonium acetate solution.
3. Shake for five min through the mechanical shaker.
4. The sample was transferred to filter after filtration, the sample was aspirated in to the atomizer of the calibrated flame photometer and reading was noted.

Plant analysis

Preparation of plant samples

The nutrient content was analyzed in grains and straw at harvest and estimated separately from the selected plants of each plot. The plant samples for estimating the dry matter production (grains and straw) from each plot at harvest is thoroughly washed with distilled water and dried in hot air oven at $60 \pm 1^\circ\text{C}$ as dry matter accumulation. Dried samples were powdered in a Willey mill to

considerable fineness before storing them in polythene bags for further analysis.

Digestion of plant samples

The processed plant samples were analyzed by micro-Kjeldahl method to determine nitrogen content. Wet digestion (di-acid) method was used for preparation of aliquot to determine P and K content in plant samples. Vanado-molybdate yellow colour method was employed for determination of phosphorus by using Spectrophotometer and Flame photometer method, for potassium as described by Jackson (1973).

Estimation of total nitrogen in plant sample

1. Weigh 0.50-1.0 g (grain/straw) dry-plant material, and then transfer quantitatively into a dry 250-ml digestion tube.
2. Add 20 mL sulfuric-salicylic acid mixture while rotating the tube to wash down any sample adhering to the neck of the tube, and allow standing 2 hours or longer with occasional swirling.
3. Add 2.5 g sodium thiosulfate through a long-stemmed funnel to the contents of the tube and swirl gently a few times, and allow standing overnight.
4. Add 4 g catalyst mixture, and 3-4 pumice boiling granules, and place tubes on the block-digester pre-heated to 400°C .
5. Place a small glass funnel in the mouth of the tubes to ensure efficient refluxing of the digestion mixture and prevent loss of H_2SO_4 , and proceed with the digestion until the mixture clears.
6. Remove the tubes from the block-digester and allow them to cool for about 20 minutes. Then wash down any material adhering to the neck of the tube with a minimum quantity of distilled water.
7. Thoroughly agitate the tube contents, place tubes back on the block-digester, and digest for 2 hours after clearing. No particulate material should remain in the tube after digestion.
8. After the digestion is finished, allow the digest to cool, and add water slowly shaking until the liquid level is about 2-cm below the graduation mark.
9. Allow tube to cool to room temperature, and add distilled water to bring the volume to the 250-ml mark.
10. Each batch of samples for digestion should contain at least one reagent blank (no plant), and one

chemical standard (weigh 0.1 g EDTA standard digest), and one standard plant sample.

11. Titrate the distillate by 0.1 N H₂SO₄ until a purple colour just start appearing.

Estimation of total phosphorus and potassium in plant sample

1. Weigh 0.50-1.0 g (grain/straw) of dry plant material, and transfer quantitatively into a 250-ml digestion tube.
2. Add a few pumice boiling granules, and add about 3 g catalyst mixtures using a calibrated spoon.
3. Add 10 ml concentrated H₂SO₄ using a dispenser, and stir with Vortex tube stirrer until mixed well.
4. Place tubes in a block-digester set at 100°C for 20 minutes, and remove the tubes to wash down any material adhering to the neck of the tube with the same concentrated H₂SO₄.
5. Thoroughly agitate the tube contents, and then place the tubes back on the block-digester set at 380°C for 2 hours after clearing.
6. After digestion is complete, remove tubes, cool, and bring to 100-mL volume with distilled water.
7. Each batch of samples for digestion should contain at least one reagent blank (no plant), and one chemical standard (weigh 0.1 g EDTA standard digest), and one standard plant sample (internal reference).

Formula:

$$\text{P content of sample (\%)} = A/100 V$$

Where,

A = P concentration in µg as read against the sample reading on the standard curve.

V = Volume of aliquot taken for colour development out of the 100 ml acid digest made from 1 g sample.

Nutrients Uptake by crop

After estimating the nitrogen, phosphorus and potassium content in grain and straw, the uptake of these nutrients was calculated as kg ha⁻¹ by multiplying the contents with grain and straw yields in different treatments.

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \text{Nutrient (\% in grains/straw} \times \text{yield of grains/straw (q ha}^{-1}\text{)}$$

Protein content in grains

Protein content in grains of rice at maturity was worked out by multiplying the nitrogen

percentage of grains with 5.75 (AOAC, 1990).

Nutrient Use Efficiencies

Nutrient Use Efficiency is the amount of dry matter produced per unit of nutrient applied or absorbed (Mosier *et al.*, 2004). It was calculated in the following ways:

Agronomic Efficiency:

Agronomic efficiency is the economic produce obtained per unit of nutrient applied. It was calculated by the following equation:

$$AE = \frac{Yf(\text{kg/ha}) - Yc(\text{kg/ha})}{Na(\text{kg/ha})}$$

Where,

AE = Agronomic Efficiency

Yf = Yield from fertilized plot (kg/ha)

Yc = Yield from control plot (kg/ha)

Na = Nutrient applied (kg/ha)

Physiological Efficiency:

Physiological efficiency is the Dry matter production obtained per unit of nutrient uptake. It was calculated by the following equation:

$$PE = \frac{DmF(\text{kg}) - DmC(\text{kg})}{NupF(\text{kg}) - NupC(\text{kg})}$$

Where,

PE = Physiological Efficiency

DmF = Dry matter produced in fertilized plot (kg/ha)

DmC = Dry matter produced in control plot (kg/ha)

NupF = Nutrient uptake from fertilized plot (kg/ha)

NupC = Nutrient uptake from control plot (kg/ha)

Apparent Recovery Efficiency:

The apparent recovery efficiency is the quantity of nutrient absorbed per unit of nutrient applied. It was calculated by the following equation:

$$RE = \frac{NupF - NupC}{Na} \times 100$$

Where,

RE = Apparent Recovery Efficiency

NupF = Nutrient uptake from fertilized plot (kg/ha)

NupC = Nutrient uptake from control plot (kg/ha)

Na = Nutrient applied (kg/ha)

Partial Factor Productivity:

The partial factor productivity is the measure of crop yield produced per unit of nutrient applied. It was calculated by the following equation:

$$PFP = \frac{Y(kg/ha)}{Na(kg/ha)}$$

Where,

PFP = Partial Factor Productivity

Y = Grain Yield (kg/ha)

Na = Nutrient applied (kg/ha)

Economic studies

The cost of cultivation was calculated by taking into account the cost of seed, fertilizers, biocide, and the hiring charges of labor and machines for land preparation, irrigation, fertilizer application, plant protection, harvesting, and threshing, and the time required per hectare to complete an individual field operation. Cost of irrigation was calculated by multiplying time (h) required to irrigate a particular plot, consumption of diesel by the pump (L h⁻¹) and cost of diesel. Gross income is the minimum support price offered by the Government of India for rice. Net income was calculated as the difference between gross income and total cost.

Cost of cultivation (Rs ha⁻¹)

Cost of cultivation was worked out taking into account the fixed and variable cost of various inputs treatment wise. The input prices that prevailed during the period of experimentation was used for computing input cost prices per unit of inputs and the cost incurred in various operations.

Gross return (Rs ha⁻¹)

The monetary returns obtained from marketable produce (grain and straw) was computed by multiplying output quantity and their unit price as follows.

Gross return (Rs. ha⁻¹)

= Return from grains + Return from straw

Monetary return grain (Rs ha⁻¹)

= Grain yield (q ha⁻¹) x minimum support price (Rs /q.)

Monetary return straw (Rs ha⁻¹) = Straw yield (q ha⁻¹) x local price (Rs /q.)

Net return (Rs ha⁻¹)

The net profit was computed as difference between gross return and cost incurred on cultivation and expressed in Rs ha⁻¹ as follows.

Results and Discussion

Effect of irrigation scheduling and fertility management, Protein content (%), Protein yield (q ha⁻¹), Nitrogen content and uptake by grain and straw, Total Nitrogen uptake (kg ha⁻¹), Phosphorus content (%) and uptake by grain and straw, Potassium content (%) and uptake by grain and straw, Agronomic N-use efficiency (AEs), Physiological use efficiency, Partial Factor Productivity, Irrigation water use efficiency (kg ha⁻¹ cm), Cost of cultivation (Rs ha⁻¹), Gross return (Rs ha⁻¹) stages of crop development are described here.

Effect of irrigation scheduling and fertility management on protein content (%) and protein yield (kg ha⁻¹) of rice

Protein content (%)

Significantly differed with fertility management treatments. The treatment N₆ (150% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT) recorded maximum protein content (7.8%) which was significantly at par with N₄ (125% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT). The lowest protein content (%) recorded in N₁ (100% RDN: 4 equal splits at 15, 30, 45 & 60 DAT) treatment.

Protein yield (q ha⁻¹)

Data reveals that various irrigation scheduling and fertility management exerted significant on protein yield of rice (Table 1)

Table 1 Effect of irrigation scheduling and fertilizer management on protein content (%) and protein yield (kg ha⁻¹) of Basmati rice

Treatments		Protein content (%)	Protein yield (kg ha ⁻¹)
(A) Irrigation Scheduling			
I1	IW/CPE 0.8 throughout the growth stage	7.1	265.6
I2	IW/CPE 0.8 upto panicle initiation stage & thereafter IW/CPE 1.0 upto dough stage	7.2	310.3
I3	IW/CPE 0.8 upto panicle stage and thereafter 1.2 upto dough stage	7.8	354.2
I4	IW/CPE 1.0 throughout growth stage	7.3	307.9
I5	IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage	7.9	373.8
SE(m)±		0.04	7.45
C.D. (P=0.05)		NS	22.32
(B) Fertilizer Management			
N1	100% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	6.9	254.4
N2	100% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	7.1	284.7
N3	125% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	7.2	306.4
N4	125% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	7.6	359.2
N5	150% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	7.4	334.2
N6	150% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	7.8	380.5
SE(m)±		0.05	7.81
C.D. (P=0.05)		0.15	23.40

Among the irrigation scheduling, highest protein yield (373.8 kg ha⁻¹) was obtained with the application of I5 (IW/CPE 1.0 up to panicle initiation stage and thereafter IW/CPE 1.2 up to dough stage) which was at par with I₃ (IW/CPE 0.8 up to panicle stage and thereafter 1.2 up to dough stage). The lowest protein yield recorded in I₁ (IW/CPE 0.8 throughout the growth stage).

Data revealed that different fertility management had a significant effect on protein yield. Different fertility management practices differed significantly among themselves. The maximum protein yield (380.5 kg ha⁻¹) was found under the treatment N₆ (150% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT) which was statistically at par with the treatment N₄ (125% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT). The treatment N₁ (100% RDN: 4 equal splits at 15, 30, 45 & 60 DAT) obtained significantly lowest protein yield.

Nutrient content

Nitrogen content and uptake by grain and straw

The data on nitrogen content in grain and straw as influenced by various treatments are presented in Table 2 and illustrated in Fig 4.8 and their analysis of variance is given in appendix VIII.

A critical study of the data on nitrogen content in grain and straw revealed significant variation due to irrigation scheduling. Nitrogen content in grain increased progressively with irrigation scheduling. The treatment I₅ (IW/CPE 1.0 up to panicle initiation stage and thereafter

IW/CPE 1.2 upto dough stage) have recorded highest nitrogen content (1.38%) in grain, which was at par with I₃ (IW/CPE 0.8 upto panicle stage and thereafter 1.2 upto dough stage). The lowest nitrogen content in grain recorded in I₁ (IW/CPE 0.8 throughout the growth stage).

Table 2 Effect of irrigation scheduling and fertilizer management on nitrogen content (%) and uptake (kg ha⁻¹) of Basmati rice

Treatments		Nitrogen content (%)		Nitrogen uptake (kg ha-1)		Total uptake (kg ha ⁻¹)
		Grains	Straw	Grains	Straw	
(A) Irrigation Scheduling						
I1	IW/CPE 0.8 throughout the growth stage	1.23	0.42	46.0	25.4	71.4
I2	IW/CPE 0.8 upto panicle initiation stage & thereafter IW/CPE 1.0 upto dough stage	1.25	0.44	53.9	28.6	82.5
I3	IW/CPE 0.8 upto panicle stage and thereafter 1.2 upto dough stage	1.36	0.47	61.7	31.6	93.3
I4	IW/CPE 1.0 throughout growth stage	1.27	0.45	53.6	29.8	83.4
I5	IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage	1.38	0.49	65.3	33.6	98.9
SE(m)±		0.003	0.001	0.88	0.68	1.61
C.D. (P=0.05)		0.009	0.004	2.62	2.01	4.81
(B) Fertilizer Management						
N1	100% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	1.20	0.41	44.2	22.4	66.7
N2	100% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	1.23	0.43	49.3	26.6	75.9
N3	125% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	1.26	0.44	53.6	28.3	81.9
N4	125% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	1.33	0.48	62.9	33.2	96.1
N5	150% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	1.28	0.45	57.8	30.9	88.7
N6	150% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	1.36	0.49	66.3	34.3	100.7
SE(m)±		0.005	0.003	1.32	0.92	2.10
OC.D. (P=0.05)		0.015	0.009	3.94	2.74	6.26

Different irrigation scheduling differed significantly among themselves with respect to nitrogen content in grain. With regard to nitrogen content in straw, the treatment I₅ (IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage) recorded significantly highest value (0.49%), which was at par with I₃ (IW/CPE 0.8 upto panicle stage and thereafter 1.2 upto dough stage). The nitrogen content in both grain and straw was recorded lowest under the treatment I₁ (IW/CPE 0.8 throughout the growth stage).

There was significant difference in nitrogen content in grain and straw due to fertility management treatments. The highest nitrogen content in both grain and straw was observed highest (1.36 and 0.49% respectively) under the treatment N₆ (150% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT) which was statistically at par with N₄ (125% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT) treatments.

The study of the data on nitrogen uptake by grain and straw revealed significant variation due to irrigation scheduling. Nitrogen uptake by grain and straw increased progressively with irrigation scheduling.

The treatment I₅ (IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage) have recorded highest nitrogen uptake (65.3 and 33.6 kg ha⁻¹) by grain and straw, which was at

par with I₃ (IW/CPE 0.8 upto panicle stage and thereafter 1.2 upto dough stage), respectively. The nitrogen uptake by both grain and straw was recorded lowest under the treatment I₁ (Pre sowing irrigation + One irrigation at pre bloom stage).

There was a significant difference in nitrogen uptake by grain and straw due to fertility management. The highest nitrogen uptake by both grain and straw was observed highest (66.3 and 34.3, respectively) under the treatment N₆ (150% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT), which was at par with N₄ (125% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT). The significantly lowest nitrogen uptake by grain and straw was recorded under the treatment N₁ (100% RDN : 4 equal splits at 15, 30, 45 & 60 DAT).

Total Nitrogen uptake (kg ha⁻¹)

A critical study of the data on total nitrogen uptake revealed significant variation due to irrigation scheduling. Total nitrogen uptake increased progressively with irrigation scheduling. The treatment I₅ (IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage) have recorded highest total nitrogen uptake (98.9 kg ha⁻¹), which was at par with I₃ (IW/CPE 0.8 upto panicle stage and thereafter 1.2 upto dough stage). The lowest total nitrogen uptake recorded in I₁ (IW/CPE 0.8 throughout the growth stage).

There was a significant difference in total nitrogen uptake due to fertility management. The highest total nitrogen uptake was observed highest (100.7 kg ha⁻¹) under the treatment N₆ (150% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT), which was at par with N₄ (125% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT). The significantly lowest total nitrogen uptake was recorded under the treatment N₁ (100% RDN: 4 equal splits at 15, 30, 45 & 60 DAT).

Phosphorus content (%) and uptake by grain and straw

Data pertaining to phosphorus content in grain and straw are summarized in Table 3 .

Table 3 Effect of irrigation scheduling and fertilizer management on phosphorus content (%) and uptake (kg ha⁻¹) of Basmati rice

Treatments		Phosphorus content (%)		Phosphorus uptake (kg ha ⁻¹)		Total uptake (kg ha ⁻¹)
		Grains	Straw	Grains	Straw	
(A) Irrigation Scheduling						
I1	IW/CPE 0.8 throughout the growth stage	0.32	0.15	12.0	9.1	21.1
I2	IW/CPE 0.8 upto panicle initiation stage & thereafter IW/CPE 1.0 upto dough stage	0.33	0.16	14.2	10.4	24.6
I3	IW/CPE 0.8 upto panicle stage and thereafter 1.2 upto dough stage	0.37	0.19	16.8	12.8	29.5
I4	IW/CPE 1.0 throughout growth stage	0.34	0.17	14.3	11.3	25.6
I5	IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage	0.39	0.20	18.5	13.7	32.2
SE(m)±		0.002	0.003	0.51	0.32	0.94
C.D. (P=0.05)		0.004	0.009	1.52	0.94	2.80
(B) Fertilizer Management						
N1	100% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	0.31	0.14	11.4	7.7	19.1
N2	100% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	0.33	0.15	13.2	9.3	22.5
N3	125% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	0.34	0.16	14.5	10.3	24.8
N4	125% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	0.36	0.19	17.0	13.2	30.2
N5	150% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	0.35	0.17	15.8	11.7	27.5
N6	150% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	0.38	0.20	18.5	14.0	32.6
SE(m)±		0.003	0.003	0.68	0.48	1.14
C.D. (P=0.05)		0.009	0.007	2.02	1.42	3.40

A keen examination of the data revealed that various irrigation scheduling significantly influenced phosphorus content and uptake by grain and straw. The highest phosphorus content (0.39 and 0.20%, respectively) in grain as well as straw was recorded under the treatment I₅ (IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage) which was statistically at par with I₃ (IW/CPE 0.8 upto panicle stage and thereafter 1.2 upto dough stage) treatment. The highest phosphorus uptake by grain as well as straw was recorded under the treatment I₅ (IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage) which was statistically at par with I₃ (IW/CPE 0.8 upto panicle stage and thereafter 1.2 upto dough stage) treatment. The lowest phosphorus content and uptake recorded in I₁ (IW/CPE 0.8 throughout the growth stage) plot.

Marked effect of fertility management was observed on grain as well as straw phosphorus content. Application of N₆ (150% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT) recorded maximum phosphorus content in grain and straw. This treatment was superior over all treatments with respect to grain and straw phosphorus content. The highest phosphorus uptake by grain and straw was recorded under N₆ (150% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT). The lowest phosphorus content and uptake recorded in N₆ (150% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT) plot.

Potassium content (%) and uptake by grain and straw

Data on potassium content and uptake by grain and straw (Table 4) indicated that there was a gradual change in potassium content and uptake with increasing scheduling of irrigation. The potassium content in grain as well as straw was found highest (0.50 and 1.36%) under I₅ (IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage) followed by I₃ (IW/CPE 0.8 upto panicle stage and thereafter 1.2 upto dough stage). The lowest potassium content and uptake by both grain and straw was recorded under the treatment I₁ (IW/CPE 0.8 throughout the growth stage). Fertility management caused significant variation in potassium content in grain and straw of rice. Application of N₆ (150% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT) recorded maximum potassium content in grain and straw as 0.49 and 1.36%, respectively, which was at par with N₄ (125% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT) treatment. The potassium uptake by grain and straw was also found highest under the treatment N₆ (150% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT) which was at par with N₄ (125% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT). The lowest potassium uptake was recorded with the application of N₁ (100% RDN: 4 equal splits at 15, 30, 45 & 60 DAT) in case of both grain and straw.

Table 4 Effect of irrigation scheduling and fertilizer management on potassium content (%) and uptake (kg ha⁻¹) of Basmati rice

Treatments		Potassium content (%)		Potassium uptake (kg ha ⁻¹)		Total uptake (kg ha ⁻¹)
		Grains	Straw	Grains	Straw	
(A) Irrigation Scheduling						
I1	IW/CPE 0.8 throughout the growth stage	0.44	1.27	16.5	76.9	93.4
I2	IW/CPE 0.8 upto panicle initiation stage & thereafter IW/CPE 1.0 upto dough stage	0.45	1.29	19.4	83.9	103.3
I3	IW/CPE 0.8 upto panicle stage and thereafter 1.2 upto dough stage	0.48	1.34	21.8	90.2	112.0
I4	IW/CPE 1.0 throughout growth stage	0.46	1.31	19.4	86.8	106.2
I5	IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage	0.50	1.36	23.7	93.2	116.9
SE(m) ±		0.003	0.004	0.68	1.66	2.16
C.D. (P=0.05)		0.010	0.012	2.02	4.96	6.45

(B) Fertilizer Management						
N1	100% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	0.42	1.24	15.5	67.9	83.4
N2	100% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	0.44	1.28	17.6	79.2	96.8
N3	125% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	0.45	1.29	19.2	82.9	102.0
N4	125% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	0.48	1.33	22.7	92.1	114.8
N5	150% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	0.46	1.31	20.8	89.8	110.6
N6	150% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	0.49	1.36	23.9	95.3	119.2
SE(m)±		0.004	0.005	0.74	1.85	2.38
C.D. (P=0.05)		0.011	0.013	2.20	5.52	7.12

Nutrient use efficiencies

Agronomic N-use efficiency (AE_s)

Data on agronomic use efficiency (Table 5) indicated that there was a gradual change in agronomic use efficiency with increasing scheduling of irrigation. The agronomic use efficiency was found highest (6.6, 16.5 and 24.8) under I₅ (IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage) which was at par with I₃ (IW/CPE 0.8 upto panicle stage and thereafter 1.2 upto dough stage). The lowest agronomic use efficiency was recorded under the treatment I₁ (IW/CPE 0.8 throughout the growth stage).

Fertility management caused significant variation in agronomic use efficiency of rice. Application of N₆ (150% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT) recorded maximum agronomic use efficiency as 7.9, 19.8 and 29.8, respectively, which was at par with N₄ (125% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT) treatment. The lowest agronomic use efficiency recorded in N₁ (100% RDN: 4 equal splits at 15, 30, 45 & 60 DAT) treatment.

Table 5 Effect of irrigation scheduling and fertilizer management on Agronomic Use Efficiency

Treatments		Agronomic use-efficiency (AE)		
		Nitrogen (N)	Phosphorus (P)	Potassium (K)
(A) Irrigation Scheduling				
I1	IW/CPE 0.8 throughout the growth stage	0.0	0.0	0.0
I2	IW/CPE 0.8 upto panicle initiation stage & thereafter IW/CPE 1.0 upto dough stage	3.8	9.5	14.2
I3	IW/CPE 0.8 upto panicle stage and thereafter 1.2 upto dough stage	5.3	13.3	19.9
I4	IW/CPE 1.0 throughout growth stage	3.2	8.0	11.9
I5	IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage	6.6	16.5	24.8
SE(m)±		0.6	1.1	1.7
C.D. (P=0.05)		1.8	3.3	5.1
(B) Fertilizer Management				
N1	100% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	0.0	0.0	0.0
N2	100% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	2.1	5.4	8.0
N3	125% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	3.8	9.5	14.2
N4	125% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	6.9	17.3	26.0
N5	150% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	5.5	13.8	20.7
N6	150% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	7.9	19.8	29.8
SE(m)±		0.8	1.4	1.9
C.D. (P=0.05)		2.3	4.1	5.6

Physiological use efficiency

Data on physiological use efficiency (Table 6) indicated that there was a gradual change in physiological use efficiency with increasing scheduling of irrigation.

The physiological use efficiency was found highest (51.3, 162.6 and 57.5) under I₂ (IW/CPE 0.8 upto panicle initiation stage & thereafter IW/CPE 1.0 upto dough stage) followed by I₄ (IW/CPE 1.0 throughout growth stage). The lowest physiological use efficiency was recorded under the treatment I₅ (IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage).

Fertility management caused significant variation in physiological use efficiency of rice. Application of N₃ (125% RDN: 4 equal splits at 15, 30, 45 & 60 DAT) recorded maximum physiological use efficiency as 37.6, 99.6 and 33.2, respectively followed by N₅ (150% RDN: 4 equal splits at 15, 30, 45 & 60 DAT) treatment. The lowest physiological use efficiency recorded in N₂ (100% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT).

Table 6 Effect of irrigation scheduling and fertilizer management on physiological use efficiency

Treatments		Physiological use-efficiency (PE)		
		Nitrogen (N)	Phosphorus (P)	Potassium (K)
(A) Irrigation Scheduling				
I ₁	IW/CPE 0.8 throughout the growth stage	0.0	0.0	0.0
I ₂	IW/CPE 0.8 upto panicle initiation stage & thereafter IW/CPE 1.0 upto dough stage	51.3	162.6	57.5
I ₃	IW/CPE 0.8 upto panicle stage and thereafter 1.2 upto dough stage	36.3	94.8	42.8
I ₄	IW/CPE 1.0 throughout growth stage	39.8	106.0	37.3
I ₅	IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage	36.0	89.3	42.2
SE(m)±		4.1	20.5	5.2
C.D. (P=0.05)		3.3	61.4	15.5
(B) Fertilizer Management				
N ₁	100% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	0.0	0.0	0.0
N ₂	100% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	35.0	94.7	24.0
N ₃	125% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	37.4	99.6	30.5
N ₄	125% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	35.3	93.5	33.1
N ₅	150% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	37.6	98.6	30.4
N ₆	150% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	35.0	88.1	33.2
SE(m)±		2.3	6.7	1.2
C.D. (P=0.05)		6.8	20.1	3.5

Partial Factor Productivity

Data on partial factor productivity (Table 7) indicated that there was a gradual change in partial factor productivity with increasing scheduling of irrigation.

The partial factor productivity was found highest (31.5, 78.9 and 118.3) under I₅ (IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage) which was at par with I₃ (IW/CPE 0.8 upto panicle stage and thereafter 1.2 upto dough stage). The lowest partial factor productivity was recorded under the treatment I₁ (IW/CPE 0.8 throughout the growth stage).

Fertility management caused significant variation in partial factor productivity of rice. Application of N₆ (150% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT) recorded maximum partial factor productivity as 32.5, 81.3 and 122.0, respectively which was at par with N₄ (125% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT) and N₅ (150% RDN: 4 equal splits at 15, 30, 45 & 60 DAT) treatments. The lowest partial factor productivity recorded in N₁ (100% RDN: 4 equal splits at 15, 30, 45 & 60 DAT) treatment.

Table 7 Effect of irrigation scheduling and fertilizer management on Partial Factor Productivity

Treatments		Partial factor productivity		
		Nitrogen (N)	Phosphorus (P)	Potassium (K)
(A) Irrigation Scheduling				
I1	IW/CPE 0.8 throughout the growth stage	24.9	62.4	93.5
I2	IW/CPE 0.8 upto panicle initiation stage & thereafter IW/CPE 1.0 upto dough stage	28.7	71.8	107.8
I3	IW/CPE 0.8 upto panicle stage and thereafter 1.2 upto dough stage	30.2	75.6	113.4
I4	IW/CPE 1.0 throughout growth stage	28.1	70.3	105.5
I5	IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage	31.5	78.9	118.3
SE(m)±		1.2	2.3	3.1
C.D. (P=0.05)		3.5	6.8	9.2
(B) Fertilizer Management				
N1	100% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	24.6	61.5	92.2
N2	100% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	26.7	66.8	100.3
N3	125% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	28.4	70.9	106.4
N4	125% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	31.5	78.8	118.2
N5	150% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	30.1	75.3	112.9
N6	150% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	32.5	81.3	122.0
SE(m)±		1.8	2.9	3.8
C.D. (P=0.05)		5.3	8.6	11.3

Water studies

Irrigation water use efficiency (kg ha⁻¹ cm)

The information about irrigation scheduling and water use efficiency under different irrigation scheduling is summarized in Table 8 .

According to the findings, the effectiveness of irrigation water consumption varied considerably in response to various irrigation scheduling in rice during year of experimentation. The maximum irrigation water use efficiency, nevertheless, was obtained by treatment I₅ (IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage), which was at par with I₃ (IW/CPE 0.8 upto panicle stage and thereafter 1.2 upto dough stage). The lowest irrigation water use efficiency recorded in I₁ (IW/CPE 0.8 throughout the growth stage).

A review of the data revealed that, the IW/CPE ratio had a considerable impact on how much water was used to irrigate in rice. Treatment N₆ (150% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT) recorded highest irrigation water use efficiency among the various fertility management options, which was at par with N₄ (125% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT). The lowest irrigation water use efficiency recorded in N₁ (100% RDN: 4 equal splits at 15, 30, 45 & 60 DAT) treatment, no statistically significant correlations between irrigation scheduling and fertility management were discovered.

Table 8 Effect of irrigation scheduling and fertilizer management on consumptive use (cm) and water use efficiency (q ha⁻¹ cm) of rice

		Grain yield (q ha ⁻¹)	Consumptive use (cm)	Water use efficiency (%)
(A) Irrigation Scheduling				
I1	IW/CPE 0.8 throughout the growth stage	37.41	25.9	1.44
I2	IW/CPE 0.8 upto panicle initiation stage & thereafter IW/CPE 1.0 upto dough stage	43.10	24.6	1.75
I3	IW/CPE 0.8 upto panicle stage and thereafter 1.2 upto dough stage	45.37	21.7	2.09
I4	IW/CPE 1.0 throughout growth stage	42.18	23.7	1.78

I5	IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage	47.32	17.1	2.77
Mean		43.08	22.60	1.97
(B) Fertilizer Management				
N1	100% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	36.88	26.8	1.38
N2	100% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	40.10	24.2	1.66
N3	125% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	42.56	23.4	1.82
N4	125% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	47.26	21.5	2.20
N5	150% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	45.16	22.1	2.04
N6	150% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	48.78	17.4	2.80
Mean		43.46	22.57	1.98

Water productivity (kg m⁻³ applied water)

According to the data on water productivity presented in Table 9, the water productivity of rice was significantly impacted by the various irrigation scheduling. Water productivity was noticeably higher in treatment I₅ (IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage) but was still equivalent to I₂ (IW/CPE 0.8 upto panicle initiation stage & thereafter IW/CPE 1.0 upto dough stage). Year of experimentation, conservation-based irrigation scheduling was demonstrated to be superior over I₁ (IW/CPE 0.8 throughout the growth stage).

Table 9 Effect of irrigation scheduling and fertilizer management on total water applied (cm) and water productivity (kg cm⁻³) of rice

Treatments		Grain yield (q ha ⁻¹)	Total water applied (cm)	Water productivity (kg cm ⁻³)
(A) Irrigation Scheduling				
I1	IW/CPE 0.8 throughout the growth stage	37.4	42.6	0.88
I2	IW/CPE 0.8 upto panicle initiation stage & thereafter IW/CPE 1.0 upto dough stage	43.1	40.5	1.06
I3	IW/CPE 0.8 upto panicle stage and thereafter 1.2 upto dough stage	45.4	35.8	1.27
I4	IW/CPE 1.0 throughout growth stage	42.2	37.1	1.14
I5	IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage	47.3	22.3	2.12
Mean		43.08	35.6	1.29
(B) Fertilizer Management				
N1	100% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	36.8	40.8	0.90
N2	100% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	40.1	38.2	1.05
N3	125% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	42.5	36.8	1.15
N4	125% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	47.2	31.6	1.49
N5	150% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	45.1	34.6	1.30
N6	150% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	48.8	21.7	2.25
Mean		43.46	33.9	1.35

Effect of irrigation scheduling and fertilizer management on economics of rice

Cost of cultivation (Rs ha⁻¹)

The data pertaining to cost of cultivation is presented in Table 10. The data indicates the

highest cost of cultivation (Rs. 38700) was observed in the treatment I₅ (IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage) which was applied in the treatment followed by I₃ (IW/CPE 0.8 upto panicle stage and thereafter 1.2 upto dough stage). The

lowest cost of cultivation (Rs. 29687) observed in I₁ (IW/CPE 0.8 throughout the growth stage) plots. Under different fertility management the highest cost of cultivation (Rs. 39865) was observed in N₆ (150% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT) which was applied in the treatment followed by N₄ (125% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT) and N₅ (150% RDN : 4 equal splits at 15, 30, 45 & 60 DAT). The lowest cost of cultivation (Rs. 30962) observed in N₁ (100% RDN: 4 equal splits at 15, 30, 45 & 60 DAT) treatment.

Gross return (Rs ha⁻¹)

The data pertaining to gross return is presented in Table 10. The data indicates the highest gross return (Rs. 132008) was observed in the treatment I₅ (IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage) followed by I₃ (IW/CPE 0.8 upto panicle stage and thereafter 1.2 upto dough stage).

The lowest gross return (Rs. 105245) observed in I₁ (IW/CPE 0.8 throughout the growth stage) plots.

Net returns (Rs ha⁻¹)

The data pertaining to net return is presented in Table 10. The data indicates the highest net return (Rs. 93308) was observed in the treatment I₅ (IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage) followed by I₃ (IW/CPE 0.8 upto panicle stage and thereafter 1.2 upto dough stage). The lowest net return (Rs. 75558) observed in I₁ (IW/CPE 0.8 throughout the growth stage) plots. Different fertility management the highest net return (Rs. 96099) was observed in N₆ (150% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT) followed by N₄ (125% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT). The lowest net return (Rs. 72184) observed in N₁ (100% RDN: 4 equal splits at 15, 30, 45 & 60 DAT) treatment.

Table 10 Effect of irrigation scheduling and fertilizer management on economics of rice

Treatments		Cost of cultivation (? ha ⁻¹)	Gross return (? ha ⁻¹)	Net return (? ha ⁻¹)	Benefit cost ratio
(A) Irrigation Scheduling					
I1	IW/CPE 0.8 throughout the growth stage	29687	105245	75558	2.55
I2	IW/CPE 0.8 upto panicle initiation stage & thereafter IW/CPE 1.0 upto dough stage	33990	120758	86768	2.55
I3	IW/CPE 0.8 upto panicle stage and thereafter 1.2 upto dough stage	36987	126887	89900	2.43
I4	IW/CPE 1.0 throughout growth stage	35195	118700	83505	2.37
I5	IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage	38700	132008	93308	2.41
Average		34912	120720	85808	2.46
(B) Fertilizer Management					
N1	100% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	30962	103146	72184	2.33
N2	100% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	33685	112624	78939	2.34
N3	125% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	35268	119250	83982	2.38
N4	125% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	38765	132002	93237	2.40
N5	150% RDN : 4 equal splits at 15, 30, 45 & 60 DAT	37412	126616	89204	2.38
N6	150% RDN : 5 equal splits at 15, 25, 35, 45 & 60 DAT	39865	135964	96099	2.41
Average		35993	121600	85608	2.38

B: C ratio

The data pertaining to B: C ratio is presented in Table 4.18. The data indicates the highest B: C ratio (2.43) was observed in the treatment I₃ (IW/CPE 0.8 upto panicle stage and thereafter 1.2 upto dough stage) followed by I₅ (IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage). The lowest B: C ratio (2.37) observed in I₄ (IW/CPE 1.0 throughout growth stage) plots. Different fertility management the highest B: C ratio (2.41) was observed in N₆ (150% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT) followed by N₄ (125% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT). The lowest B: C ratio (2.33) observed in N₁ (100% RDN: 4 equal splits at 15, 30, 45 & 60 DAT) treatment.

Conclusion

Protein content also varied significantly due to different irrigation and fertilizer treatments. The maximum protein content was found in IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage and 150% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT. The minimum protein content was found in IW/CPE 0.8 throughout the growth stage and 100% RDN: 4 equal splits at 15, 30, 45 & 60 DAT.

The highest available nitrogen, phosphorus and potassium was observed with the application of IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage and 150% RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT while the lowest available nitrogen, phosphorus, potassium and sulphur was observed with the application of IW/CPE 0.8 throughout the growth stage and 100% RDN: 4 equal splits at 15, 30, 45 & 60 DAT.

Organic carbon content in soil after harvest of rice crop differs significantly and increased over its initial value under different treatments.

Gross income and net profit were found significantly higher with the combined application of IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage and 150%

RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT (Rs. 132008 & 135964 and Rs. 93308 & 96099), respectively over rest of treatment.

Benefit: cost ratio was significantly affected by application of IW/CPE 1.0 upto panicle initiation stage and thereafter IW/CPE 1.2 upto dough stage and 150% 3RDN: 5 equal splits at 15, 25, 35, 45 & 60 DAT alone with mean value 2.43 followed by remaining treatments.

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