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Popularizing the Cultivation of Some Aromatic Grasses under Red and Lateritic Areas of West Bengal

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INTRODUCTORY OVERVIEW

The Western part of West Bengal comprising the districts of Birbhum, Bankura, Purulia, Jhargram Parts of Paschim Medinipur and Paschim Bardhaman is under red and lateritic soil zones. Red and Lateritic soil become dry within very short period after monsoon and very much prone to soil erosion through drainage of rain water. Soil suffers from lack of nutrients and crop suffers from insufficiency of moisture due to erratic rainfall. The soils are usually low fertile owing to acidic pH, poor occurrence of organic matter, low availability of N,P, K etc. The average rainfall of these areas is around 1400 mm of which 75 – 80% occurs in monsoon during June to September. High potential evapotranspiration values, erratic distribution of rainfall and low water holding capacity of the soil tend to result in severe problem of availability of water in large parts of these districts, especially during lean season.

With all these constrains, about 80% of these available land areas are utilized for agriculture and yield remains under suboptimal level. Land utilization is also of limiting order. While *kharif* rice is extensively cultivated in monsoon period, large parts of these lands are usually remain fallow during the rest period of the year, mostly due to non availability of irrigation water. In spite of all these problems, this zone is recognized as agriculturally dependent about 70% of the total working force remaining engaged in different agricultural activities. Economy of such population is low order and the urgent need for improving the economic conditions of such resource poor people are being recognized at different levels. In view of the importance of agriculture in this belt, such efforts should preferably be made through effective manipulation and adoption of suitable and promising agro-techniques. Under this background, development of horticulture activities with special reference to medicinal and aromatic plants appears to be a promising proposition.

The Indian ecosystem contributes its rich medicinal and aromatic plants resources. There is also vast demand for essential oils and their derivatives obtained from such plants in the Indian and world markets and the demand is increasing day by day. In recent years, some of the aromatic plants have attracted the attention of many growers because they can be grown without much difficulty. They are also remunerative under rainfed condition and even relatively unfertile soils. Hence, a timely awareness programme for plantation of these aromatic plant species in the rural sectors will be highly useful for utilizing these land resources and also for improving economic conditions of these poor farmers. The aromatic grasses produce large amount of essential oil for the perfumery and cosmetic industries. Among the aromatic grass, Java citronella (*Cymbopogon winterianus* Jowitt.) and palmarosa (*Cymbopogon martini* var. *motia*) are two important grasses. Some states of the country have been able to achieve significant success in developing these aromatic grasses. No detailed information on cultivation of such plants with regard to various soil groups, especially lateritic soil belts, are lacking. Cultivation of these plants has gained popularity on account of easy culture and wide adaptability. Hence, the introduction of these aromatic grasses has been tried in lateritic zone of West Bengal comprising the districts of Birbhum, Bankura, Purulia and parts of paschim Bardhaman and paschim Medinipur where a large amount of land remain fallow uncultivated or under poor crops. Wide adoption of such technology will help in augmenting income of the farmers by growing these essential oil yielding aromatic grasses and further extraction of essential oil which also helped in overall economic growth of the area.

The programme

A programme on popularization of cultivation of Java citronella and Palmarosa grass has been targeted for the farmers of different blocks of Birbhum District viz., Sriniketan, Dubrazpur and Rajnagar to develop awareness about the package of practices for cultivation of Java citronella and palmarosa during the year 2003 to 2011. The total programme was carried out with the financial help of National Horticulture Board (NHB), Ministry of Agriculture, Govt. of India. The programme was conducted with cumulating some target works like on farm trials, analysis of herbage yield and yield attributes, extraction of essential oil and quality evaluation, economic analysis of cultivation, preparation of extension manual, training programme etc.

a. On farm trial:

On farm trials have been conducted at the above mentioned blocks which represent typical red and Lateritic soil zones of Birbhum District of West Bengal. The production technology of production of the grasses developed at Agricultural Farm under Institute of Agriculture, Calcutta University and other Research Organizations was modified according to the agro-climatic condition of red and Lateritic soil belts of West Bengal. The modifications were tested against standard cultivation practices for assessing the efficiency for being transmitted to the farmers' field after analyzing the herbage yield with yield related attributes. The modified and recommended brief package of practices for Java citronella and palmarosa are presented in table 1.

b. Extraction of essential oil and their quality evaluation:

Essential oil from the herbage of Java citronella and palmarosa were extracted separately by steam distillation method using the steam distillation unit of Division of Horticulture, Institute of Agriculture, Visva-Bharati (constructed with the funding of NHB). Essential oils were extracted from segments of the finely chopped fresh, dried or part-dried grasses of Java citronella and palmarosa. There were no appreciable differences in essential oil content among the various demonstration plots under the project. The essential oil content recorded so far had 0.90 – 0.95% in java citronella grass. However, in case of Palmarosa the range was 0.40-0.45%. The oil properties analyzed are presented in table 2.

c. Demonstration of package of practices for production of Java citronella and palmarosa:

As per the schedule of the programme, field demonstration of Java citronella and palmarosa has been done in different places of the said zone. Improved package of practices for Java citronella were carried out at the farmer's field nearby Joydev of Birbhum district and at demonstration plots of Institute of Agriculture, Visva-Bharati, Sriniketan, Birbhum. Demonstration of scientific agronomic package of palmarosa were carried out at Karidhya village, Suri, Birbhum and demonstration plots of Institute of Agriculture, Visva-Bharati, Sriniketan, Birbhum. The fields are situated in the western part of West Bengal under sub-humid tropical zone in the eastern part of India.

The soils of the sites are sandy loam in texture and acidic in nature, more or less representative of red and lateritic soils. The demonstration programme at different villages were fragmented through a large number of demonstration plots of different farmers.

d. Training Programme:

More than twelve training programmes on cultivation, extraction and utilization Java citronella and palmarosa grasses were conducted during the entire programme period at different adapted villages of Birbhum district viz. Joydeb, Suri, Bahadurpur, Thupsara and Sriniketan. A large number of farmers have directly been benefited from the training programmes. Further, it may be mentioned herewith that one TV programme was held at Joydeb on 9th January'2006 in collaboration with Doordarshan Kendra Santiniketan, Prasar Bharati, Govt. of India on

TABLE 1. Recommended package of practices and uses of Java citronella and palmarosa under red and Lateritic areas of West Bengal

Description **Botanical Name**	**Java citronella** *Cymbopogon winterianus*	**Palmarosa** (Rusa or Rosha) *Cymbopogon martini* var. *motia*
		
Climate	It prefers warm climate with plenty of sunshine and well distributed rainfall of 200-250 cm. It does not prefer draught, shade condition and prolong winter. It grows well in plains and also in hills upto 900m. However, warm, sunny place having humidity 75-90% within 180-250 m elevation is suitable for cultivation of citronella grass.	It is hardy plant and can grow in varying altitude from sea level. Warm, humid, sunny places without any shade having annual rainfall 75-150 cm are ideal for palmarosa cultivation.
Soil	Well drained rich sandy loam, having good water holding capacity, rich in organic matter having pH range from 5.0-6.5 is ideal.	It prefers well drained, neutral to alkaline soil, sandy to sandy loam in structure, rich in organic matter. Fertile soil of arid, saline, narginal to sub marginal land is also suitable.
Cultivars	RRL-JOR-3-1970, IW 31243, IW 31245, KS-CW-SI etc.	IW 31244, RRL(B)-77, RRL(B)-71, Trishna
Propagation & planting	Rooted slips are generally used as the planting materials. Rooted slips are planted in the well prepared field (raised beds) during April-May to onset of monsoon at a spacing of 90cm x 60cm and 15cm depth.	It is commercially propagated by seed. Seeds are sown in nursery beds (2.5 kg for planting 1ha) during April-September. Seedlings are transplanted in well prepared main field when they are 15cm in height at a spacing of 60-90cm in between ridges and 45-60cm within ridges.
Manures & fertilizers	A basal dose of 60kg of P and 50kg K_2O are applied with 10t/ha FYM.	In North Indian condition a fertilizer dose of 60:40:40 N P K kg/ha is

	125kg N are applied in equal splits one month after planting and after every harvest. 0.2% Zn, 0.6% Fe and 1.0% Cu are sprayed to ensure proper growth and oil yield.	applied with 10 t/ha FYM and 25kg $ZnSO_4$/ha
Irrigation	A light irrigation is given just after planting and regular irrigation is given for proper growth and development of the plant and good herbage yield.	Irrigation is given after planting and regular need based irrigation is generally advocated.
Harvesting & yield	First cutting is taken 4-5 months after planting and the successive cuttings are taken at 2 months interval. Leaves are harvested just above the growing point. Semi dried leaves are chopped before steam distillation. An average oil yield of 140-150kg/ha is obtained in first year, 200-300kg/ha in second and third year, 200 kg/ha in fourth year and 100 kg/ha in fifth year.	The crop is first harvested six months after planting by cutting upper third stem and leave at just blooming condition. The plantation can be maintained for 8-10 years. However, yield reduces from fifth year. The grass is dried for one week to get more oil recovery. A herbage yield of 15-20 t/ha is obtained per year and that can yield 50-60kg oil.
Uses	Java oil is starting material for extraction of citronellal and geraniol which can be converted to aroma chemicals such as ctronellol, hydroxyl citronellol, synthetic menthol. These are used in soap, perfumery, cosmetic and flavouring industries. Detergents, household cleaners, insecticides are frequently aroamted by these. Ceylon oil is used for perfuming low priced preparations like detergents, sprays, polishes and insect repellants.	The oils are used as base for the fine perfumery and are valued for high geraniol content. The oil is used to impart rose like aroma in different soaps, tioleteries, and tobacco products.

prospect of cultivation of citronella grass with special reference to the present programme.

Present condition and future scope of the programme:

A considerable number of beneficiary farmers responded for cultivate Java citronella and palmarosa grasses in their own land initially collecting the elite planting materials distributed from the Institute of Agriculture, Visva-Bharati as a part of the programme. As there is no such facility of distillation of herbage for extraction of essential oil the farmers have the only option to sell their herbage to the essential oil industries through the middlemen. However, they can directly sell the essential oil to fetch the better remuneration after extraction from the herbage produced in their won field from any local distillation units which may be set up through the Govt. initiative and monetary support. As the agriculture is limited to only few field crops mostly during the monsoon and huge area remains fallow throughout the year in red and lateritic soil zone, where there is a great scope of cultivation of such oil

TABLE 2. Properties of Java citronella oil and palmarosa oil:

Oil properties	Java citronella oil	Palmarosa oil
Oil recovery	1.0-1.5 %	0.5 – 0.8 %
Major oil components	Citronellal 30-38%, geraniol 12-18%, citronellol 11-15%, geranyl acetate 3-8% in oil.	Geraniol 95% and linalool, alpha-terpineol, geranyl isobutyrate etc. remaining 5 % in oil.
		

yielding grasses. This cultivation will not only improve the economic status of the local people through but also a value chain can be developed for production and export of quality essential oils. A large number of young people may get employed at different stages of the value chain starting from the production of raw materials, extraction of oil, its processing and value addition. On the other hand the soil erosion and can be checked by plantation of these grasses to barren undulated land. The green cover of such grass plantation may also be considered as the instrumental for reducing the heat island effect of entire red and lateritic zone of West Bengal including adjoining districts of Jharkhand, Bihar, Orissa and Chhattish Garh where the increasing area under mining are causing the spread of air and thermal pollution. Thus an effortful extension activity should be an important consideration for cultivation of such essential oil yielding grasses including the creation of market promotion. For providing the facility of extraction of essential oils from the herbage, distillation units may be set up at village level or at least block level by Government initiative through co-operative system for the farmers. Processing and value addition of such essential oils for better remuneration may also be promoted through the local cottage industry organized by the unemployed local youth. The demand of essential oils is increasing day by day in national and international markets for preparation of herbal products. Being an important component of natural herbal cosmetics, the production, processing, value addition and marketing of such essential oils may be great boon for the Indian farmers in general and Eastern India in particular.

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Effect of Bio- Fertilizer on Growth and Yield of Cauliflower and Soil Fertility Status

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Abstract

A field experiments was conducted at farmer's field of Gobrachh village, Kaimur distrct of Bihar to find out the effect of conjoint application of organic and inorganic sources of cauliflower. Four technology option was taken as Tech. Op. 1: Farmer's Practice; Tech. Op. 2: 100% RDF; Tech. Op. 3: 75% RDF+100 q vermicompost ha^{-1}; Tech. Op. 4: 75% RDF+ 100 q vermicompost +2.5 kg PSB+2.5 kg Azotobacter ha^{-1}. The curd weight of cauliflower increased significantly by application of 75% RDF along with biofertilizer (Tech. Op. III) over Farmer's practice. The yield of cauliflower was significantly increased by application 100% RDF along with biofertilizer (Tech. Op. III) over Farmer's practice. Initial trends indicated that application of micronutrient and biofertilizer perhaps increased N, P, K and Zn in soil.

Key words: *Cauliflower, Urea, DAP, MOP, Vermicompost, PSB, Azotobacter*

Introduction

Cauliflower (*Brassica oleracea* L. var. *botrytis*), member of family Crucifier is one of the most important vegetable crops grown extensively in sub-temperate climate throughout the world. It is an important commercial vegetable crop grown in India and is good source of vitamin a and c and contains minerals like potassium, sodium, calcium, iron, phosphorus, magnesium. It is a heavy feeder of mineral elements; it removes large number of macronutrients from the soil. So, it demands constant supply of large amount of nutrients and water for its luxuriant growth. Cauliflower is the fifth most important vegetable crop in India, primarily grown in the winter season. In India cauliflower grown over an area 433.9 thousand ha with a production of about 5873.3 thousand MT/ha and productivity is 19.8 MT/ha.

Bihar is the third largest cauliflower growing state in the country with an area 36500 ha, production of 5.99 lakh tons and productivity of 16.4 tons/ha. The dramatic increase in vegetable production and the increase in fertilizer consumption point to the crucial role of fertilizers. In 2014 the highest area and production of cauliflower is in West Bengal ie.73.6 thousand ha, 1879.0 thousand MT/ha respectively (Anonymous, 2014). The Escalating prices of chemical fertilizers and its detrimental impacts had forced farmers to adopt alternative source of nutrients for vegetable production (Sharma, 2015).Therefore, to reduce use on chemical fertilizers and sustainable vegetable production are beneficial which is only possible through integrated nutrient management strategy (Merentola *et al.*, 2012). The concept of integrated nutrient management has emerged as important tool for maintaining soil fertility, crop productivity and requires optimum use of organic, inorganic and bio-sources of plant nutrients. Biofertilizers have also emerged promising components of nutrient supply system and is environment friendly and low cost input, with organic and inorganic fertilizers as part of an integrated nutrient management strategy, play significant role in plant nutrition (Vimera *et al.*, 2012). Azotobacter saves addition of nitrogenous fertilizer by 10-20% (Kumar *et al.*, 2013). It helps in translocation of food material to different parts of plant and disease and drought tolerance. The utilization of bio-fertilizers, which have a ability to enrich the soil with beneficial microorganisms as well as to mobilize the nutritionally important elements like P, K and micronutrients like Zn, Mo

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(Mishra and Dash, 2014) from non-usable to usable forms through biological processes resulting in enhanced production of fruits and vegetables offer an alternative. The use of bio-fertilizers in combination with chemical fertilizers and organic manures offers a great opportunity to increase the production as well as the quality of cauliflower. Organic manure improves soil structure and water holding capacity, resulting in more extensive root development and enhanced soil micro flora and fauna activity, which results in availability of micronutrients available to plants (Damse *et al.,* 2014). Microorganism function is in long duration, causing important of the soil fertility. It maintains the natural habitat of the soil. It increases crops yield by 20-30%, replaces chemical nitrogen and phosphorus by 25% and stimulates plant growth (Gupta *et al.,* 2015). To maintain long term soil health and productivity there is a need for integrated nutrient management through manures and bio-fertilizers apart from costly chemical fertilizers for better yield of the crop (Mondal *et al.,* 2003).

Materials and Methods

Initial soil samples were taken from the experimental field using a 5 cm diameter auger. Soil samples were mixed thoroughly, air-dried in the shade, crushed to pass through a 2 mm sieve and stored in polythene bag for analysis. Initial soil had pH 7.58-7.64, electrical conductivity (EC) 0.40-0.49 dS m^{-1}, organic carbon (OC) 3.99-4.44 g kg^{-1}, available N 182.3-203.8 kg ha^{-1}, P 14.75-15.88 kg ha^{-1}, K 119.3-186.1 kg ha^{-1}, DTPA extractable Zn 0.13-0.32(mg kg^{-1}). Observations were recorded at important physiological growth stages of cauliflower because these stages are critical for crop growth and development. Five plants were selected randomly in each plot and tagged for measuring height at different intervals. All the growth and yield attributing observations were taken at 35, 60 DAP and at harvest stage. Plant height was measured with the help of meter scale from ground surface to the tip of the top most leaf.

One month old seedlings of uniform height (about 15-20 cm) were selected and transplanted in plots of size 40 m X 25 m at spacing of 60cm X 45cm. 1/3rd dose of urea and full dose of DAP, vermicompost, PSB and Azotobacter were applied as basal dressing on the hills as per treatments with common dose of MOP. Remaining 2/3rd dose of urea was applied at two spilt doses *i.e* first at 30 days and second at 45days after transplanting. The experiment was laid out in a randomized block design in involving 8 replications and 7 technology option as Tech. Op. 1: Farmer's Practice; Tech. Op. 2: 100% RDF; Tech. Op. 3: 75% RDF+100 q vermicompost ha^{-1}; Tech. Op. 4: 75% RDF+ 100 q vermicompost +2.5 kg PSB+2.5 kg Azotobacter ha^{-1}.

Chemical analyses

The post-harvest soil samples were analyzed for pH in 1:2.5 soil: water suspension ; organic carbon (Walkley and Black 1934); available N (Subbiah and Asija 1956); NaHCO3 extractable-P (Olsen *et al.* 1954), ammonium acetate extractable K (Hanway and Heidel 1952) and post-harvest soil (PHS) samples were analyzed for DTPA extractable micronutrients (Lindsay and Norvell 1978).

Results and Discussion

A significant increase in plant height (Table 1) at 35, 60 and at harvest (DAP) was found with graded application of 75% RDF+ 100 q vermicompost +2.5 kg PSB+2.5 kg Azotobacter ha^{-1}. During the initial stage (35 DAP) of experiment, the maximum plant height (8.92 cm) was noticed in Tech. Op. 4 (75% RDF+ 100 q vermicompost +2.5 kg PSB+2.5 kg Azotobacter ha^{-1}) and the minimum (4.31 cm) in Tech. Op. 1 (FP). Similar trend was recorded in all growth stages. Subedi *et al.*, 2019 reported that maximum plant height was recorded with application of RDF along with biofertilizer due to growth promoting substances secreted by microbial inoculants and increased availability of nitrogen due to the application of the nitrogen fixing azotobacter as they fix the atmospheric nitrogen. It has been reported that secretion by these bacteria led to better root development which promoted uptake of nutrients, thus, improved the plant height (Sharma, 2002). The maximum number of leaves at 35 DAP was recorded with application of 75% RDF along with biofertilizer

Table 1. Effect of Biofertilizer on plant height, number of leaves, leaf area, curd diameter, curd weight and yield of cauliflower

Technology Option	Cauliflower	Plant Height 35 DAP (cm)	Plant Height 60 DAP (cm)	Plant Height at harvest (cm)	Number of leaves 35 DAP	Number of leaves 60 DAP
Tech. 1	Farmer's Practice (N:P:K:: 150:60:30) kg ha^{-1}	4.31	14.81	15.53	4.88	10.02
Tech. 2	100% RDF (N:P:K:: 120:80:80) kg ha^{-1}	5.36	17.03	17.67	5.83	11.00
Tech. 3	75% RDF+100 q vermicompost ha^{-1}	7.67	17.68	18.04	7.51	12.17
Tech. 4	75% RDF+ 100 q vermicompost + 2.5 kg PSB+2.5 kg Azotobactor ha^{-1}	8.92	19.79	18.85	8.68	12.88
	CD (5%)	0.14	0.23	0.22	0.23	0.25
	SEm ±	0.05	0.08	0.07	0.08	0.08
Technology Option	**Cauliflower 35 DAP (cm^2)**	**Leaf area 60DAP(cm^2)**	**Leaf area diameter (cm)**	**Curd**	**Curd weight (kg)**	**Yield (t ha^{-1})**
Tech. 1	Farmer's Practice (N:P:K:: 150:60:30) kg ha^{-1}	121.6	696.9	12.10	1.07	24.42
Tech. 2	100% RDF (N:P:K:: 120:80:80) kg ha^{-1}	131.0	776.5	15.61	1.12	26.99
Tech. 3	75% RDF+100 q vermicompost ha^{-1}	165.4	828.9	15.94	1.21	27.64
Tech. 4	75% RDF+ 100 q vermicompost + 2.5 kg PSB+2.5 kg Azotobactor ha^{-1}	239.0	1002.5	16.88	1.49	29.44
	CD (5%)	4.08	12.35	0.16	0.05	0.51
	SEm ±	1.38	4.19	0.05	0.01	0.17

(Tech. Op. 4) followed by 75% RDF along with 100 q vermicompost ha^{-1} (Tech. Op. 3) which was 78 and 54% significantly increased over Farmer's Practice (Tech. Op. 1). More numbers of leaves cause more photosynthesis which may lead to increase in curd weight, curd diameter and yield in cauliflower. Subedi *et al*., 2019 reported that in plots where biofertilizers was applied produced a greater number of leaves. Maximum leaf area 35 DAP was observed with Tec. Op. 4 (75% RDF+ 100 q vermicompost +2.5 kg PSB+2.5 kg Azotobactor ha^{-1}) followed by Tech. Op. 3 (75% RDF+100 q vermicompost ha^{-1}) and Tech. Op. 2 (100% RDF ::N:P:K:: 120:80:80: kg ha^{-1}) which was 97, 36 and 8% increased over FP (N:P:K::150:60:30 kg ha^{-1}). Similar trend was recorded in 60 DAP. The maximum curd diameter (16.88 cm) was obtained from Tech. Op. 4 (75% RDF+ 100 q vermicompost +2.5 kg PSB+ 2.5 kg Azotobactor ha^{-1}) and the minimum (12.10 cm) in Tech. Op. 1 (FP). Tech. Op. 4 receiving RDF along with micronutrients and biofertilizer (75% RDF+ 100 q vermicompost +2.5 kg PSB+2.5 kg Azotobactor ha^{-1}) significantly increased curd weight (1.49 kg) over all other tech. Op. and the increase was 39 per cent over Farmer's Practice (1.07 kg) (Table 1 and Fig. 1). The yield of cauliflower increased significantly with application of 75% RDF+ 100 q vermicompost +2.5 kg PSB+2.5 kg Azotobactor ha^{-1} (Tech. Op. 4), over Farmer's Practice (Table 1 and Fig. 1). The application of RDF along with organic manure and biofertilizer proved better in enhancing the yield parameters. The application of organic sources might have significantly enhanced the availability of native and applied macro and micro nutrients in the soil, as consequence of which the yield had been increased. Similar types of findings were reported by Srimathi, 2015.

In the post-harvest soil, pH varied from 7.67 to 7.75 (Table 2), the maximum being in Tech. Op. 2 (100% RDF (N:P:K:: 120:80:80) kg ha^{-1}) followed by Tech. Op. 4 (75% RDF+ 100 q vermicompost +2.5 kg PSB+2.5 kg Azotobactor ha^{-1}), and Tech. Op. 3 (75% RDF+100 q vermicompost ha^{-1}), and the minimum of 7.67 in Farmer's Practice (N:P:K:: 150:60:30 kg ha^{-1}). The EC of soil ranged from 0.42 to 0.47 dS m-1, with minimum in Tech. Op. 2 (100% RDF (N:P:K:: 120:80:80) kg ha^{-1}) and 3 (75% RDF+100 q vermicompost ha^{-1}), maximum in Tech. Op. 4 (75% RDF+ 100 q vermicompost +2.5 kg PSB+2.5 kg Azotobactor ha^{-1}). Application of organic and inorganic sources did not affect significantly soil pH and EC (Table 2). Gour *et al*., 2015 also reported that application of organic and inorganic sources of nutrients non significant in post harvest soil of rice pH and EC in soil. The organic carbon content of the post harvest soil varied from 4.00 to 4.80 g kg^{-1} (Table 2). Minimum organic carbon of 4.00 g kg^{-1} was found in Tech. Op. 1 (N:P:K:: 150:60:30 kg ha^{-1}), followed by 4.40 g kg^{-1} in Tech. Op. 2 (100% RDF (N:P:K:: 120:80:80 kg ha^{-1}) and 4.60 g kg^{-1} in Tech. Op. 3 (75% RDF+100 q vermicompost ha^{-1}), which was significantly lower than Tech. Op. 4 (75% RDF+ 100 q vermicompost +2.5 kg PSB+2.5 kg Azotobactor ha^{-1}). *Gour et al.* (2015) also reported higher levels of soil organic carbon under integrated treatments of organic and inorganic combinations. Available N content of post harvest soil ranged between 180.5 and 221.8 kg ha^{-1}, the minimum being in Tech. Op. 1 (FP) and the maximum in Tech. Op. 4 (75% RDF+ 100 q vermicompost +2.5 kg PSB+2.5 kg Azotobactor ha^{-1}) followed by Tech. Op. 3 (75% RDF+100 q vermicompost ha^{-1}) and Tech. Op. 2 (100% RDF::N:P:K:: 120:80:80 kg ha^{-1}). Available P in soil increased significantly with application of RDF along with organic manure and biofertilizer. Soil available P ranged between 14.63 to 28.63 kg ha^{-1}, the .minimum being in Tech. Op. 1 (FP) and the maximum in Tech. Op. 4 (75% RDF+ 100 q vermicompost +2.5 kg PSB+2.5 kg Azotobactor ha^{-1}). Available P content in soil was increased by 96.0 per cent over Tech. Op. 1 followed by Tech. Op. 2 (50.0%) and Tech. Op. 3 (27.0%). Technology 2 was at par with Tech. 3. As regards to available K content in soil (Table 3), it was minimum (116.1 kg ha^{-1}) in Tech. Op. 1 (FP) and the maximum (204.6 kg ha^{-1}) in Tech. Op. 4 (75% RDF+ 100 q vermicompost +2.5 kg PSB+2.5 kg Azotobactor ha^{-1}), which was 76.0 per cent higher over Tech. Op. 1 (FP). A significant build-up of available soil N, P and K with increase in application of RDF along with vermicompost, PSB and Azotobactor might be due to the higher content of N, P and K compounds in organic amendments which reduced nutrients losses from the

Table 2. Effect of Bio-fertilizer on soil fertility status of cauliflower

Technology Option	Cauliflower	pH	EC ($dS\ m^{-1}$)	O C ($g\ ka^{-1}$)	Initial Soil N ($kg\ ha^{-1}$)	P ($kg\ ha^{-1}$)	K ($kg\ ha^{-1}$)	Zn ($mg\ kg^{-1}$)
Tech. 1	Farmer's Practice (N:P:K:: 150:60:30) kg ha^{-1}	7.64	0.43	3.99	182.3	14.75	119.3	0.13
Tech. 2	100% RDF (N:P:K:: 120:80:80) kg ha^{-1}	7.76	0.40	4.10	200.4	15.88	127.8	0.25
Tech. 3	75% RDF+100 q vermicompost ha^{-1}	7.60	0.41	4.25	203.1	15.00	153.6	0.25
Tech. 4	75% RDF+ 100 q vermicompost + 2.5 kg PSB+2.5 kg Azotobacter ha^{-1}	7.58	0.49	4.44	203.8	15.88	186.1	0.32
CD (5%)	NS	NS	0.30	10.51	NS	7.35	0.03	
SEm ±	-	-	0.10	3.91	-	2.49	0.01	

Technology Option	Cauliflower	pH	Post harvest soil EC ($dS\ m^{-1}$)	O C ($g\ ka^{-1}$)	N ($kg\ ha^{-1}$)	P ($kg\ ha^{-1}$)	K ($kg\ ha^{-1}$)	Zn ($mg\ kg^{-1}$)
Tech. 1	Farmer's Practice (N:P:K:: 150:60:30) kg ha^{-1}	7.67	0.45	4.00	180.5	14.63	116.1	0.10
Tech. 2	100% RDF (N:P:K:: 120:80:80) kg ha^{-1}	7.75	0.42	4.40	204.0	19.13	130.6	0.34
Tech. 3	75% RDF+100 q vermicompost ha^{-1}	7.68	0.42	4.60	208.9	22.50	139.9	0.41
Tech. 4	75% RDF+ 100 q vermicompost +2.5 kg PSB+ 2.5 kg Azotobacter ha^{-1}	7.69	0.47	4.80	221.8	28.63	204.6	0.42
CD (5%)	NS	NS	0.41	9.69	3.69	6.72	0.05	
SEm ±	-	-	0.13	3.29	1.25	2.28	0.02	

soil and their build-up in post-harvest soil. The highest available Zn was recorded in Tech. Op. 4 in post harvest cauliflower soil (0.42 mg kg^{-1}) which was significantly superior to Tech. Op. 2 and Tech. Op. 3. The lowest value was recorded in Tech. Op. 1 (0.10 mg kg^{-1}) in post harvest soil of cauliflower. Zinc is an element that reacts with organic compounds with respect to its speciation, mobility and bioavailability and other molecules that form metal complexes thus total Zn in soil significantly increased over control. Kumar *et al*., 2020 also reported that conjoint application of organic and inorganic sources of nutrients recorded maximum zinc content in post harvest soil of rice- wheat system.

Conclusions

It can be concluded that curd diameter, curd weight and yield of cauliflower was significant increased with application of organic and inorganic sources of nutrients (Tech. Op. 4). It may be inferred that yield of cauliflower could be sustained by supplementing 25 % RDF for basis with Vermicompost, PSB and Azotobactor. Organic supplementation either maintained or significantly improved organic –C, available N, P, K and Zn content of the soil.

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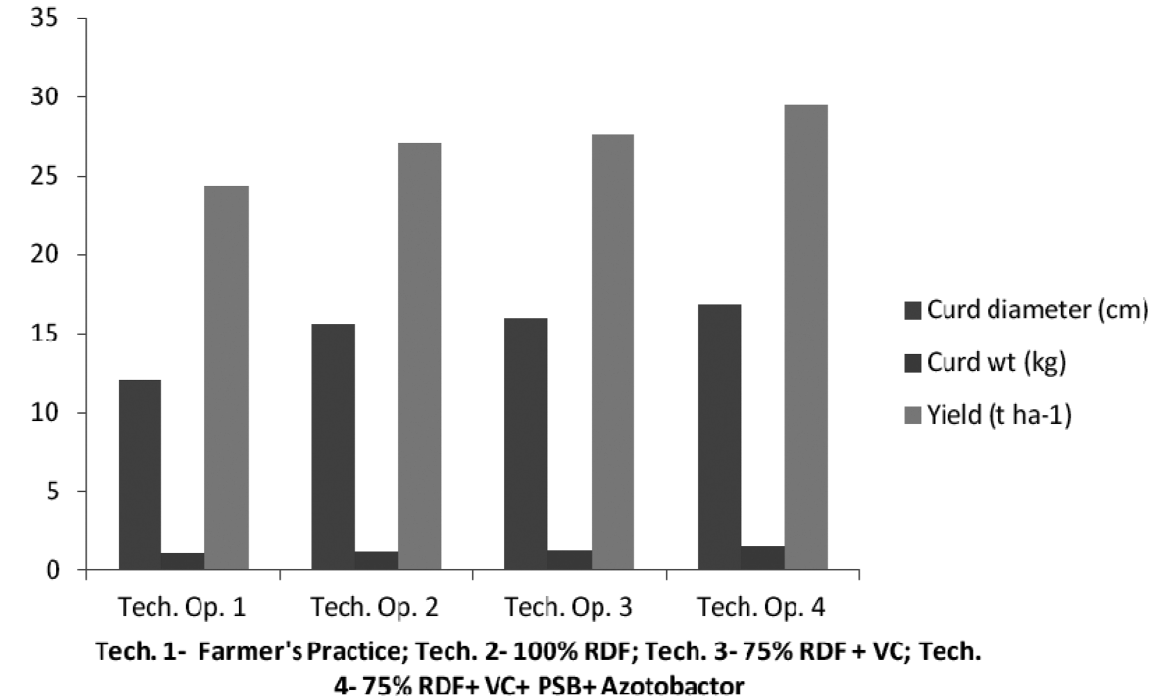

Fig. 1 Effect of Biofertilizer on curd diameter, curd weight and yield of cauliflower

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Effect of Weather and Population Dynamics of Gundhi Bug Infestation Under Staggered Planting

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Abstract

An experiment was conducted in Agrometeorology field, Central Research Farm, Orissa University of Agriculture and TechnologyBhubaneswar during 2017-2018, to study the population dynamics of Gundhi bug and its correlation with weather parameters under staggered planting with 12 dates starting from 16th July 2017 to 1st January 2018 at 15 days interval and three varieties such as Geetanjali, PoornaBhog and Pusasugandh –II. The population of GB was built up from September to April, but the highest occurrence was observed during last week of November in 1st September planting date and second peak occurrence was observed during 2nd week of September in 16th July date.

The GB population was highest when maximum temperature was 30-34^{0}c, minimum temperature (18-20^{0}c), morning relative humidity 85-88% and afternoon relative humidity 50-55%, ample sunshine hours of (9-10hr), under dry conditions found favorable for pest population.

Introduction

Rice is a crucial cereal crop globally, and the rising demand for aromatic varieties in both local and international markets has highlighted their vulnerability to insect pests, leading many farmers to discard affected crops. Key climatic factors such as rainfall, temperature, and humidity play significant roles in the development and proliferation of rice insect pests.

While paddy crops are attacked by a wide range of insect pest guilds, only a few are responsible for substantial yield losses. These pests pose a major constraint to achieving optimal rice yields, making effective pest management essential for farmers aiming to meet market demand and maintain crop health. Addressing these challenges is vital for sustaining rice production and ensuring food security.

The Gundhi bug, measuring around 19 mm in length, is characterized by its slender body, long legs, and antennae, typically exhibiting green or brown coloration. It lays oval, dark reddish-brown eggs in clusters of 10-20 on leaves, arranged in straight rows. The nymphs are slender and wingless, initially brownish-green, with their color deepening as they mature; fully grown nymphs reach about 14-16 mm.

Both adults and nymphs feed on the sap of young shoots, leaves, florets, and soft grains using their piercing, sucking mouthparts. This feeding causes white spots at the feeding sites and can lead to black or brown marks around the punctures, where sooty mold may develop. Infestation can also compromise grain quality, causing them to break easily during milling. Infested rice fields often emit a foul odor, contributing to the bug's name.

Materials and Methods

Odisha, located at an elevation of 25.9 meters above sea level and positioned at 20°15' N latitude and 85°52' E longitude, features a hot and humid climate, particularly in Bhubaneswar. In 2017, the annual mean maximum temperature reached 35.3 °C, while the mean minimum was 22.6 °C. The summer season, from March to June, is characterized by temperatures ranging from 26.4 to 35.7 °C, with May being the hottest month (32–42 °C). In contrast, the winter months of December and January are cooler and drier, with temperatures between 15 and 28 °C.

The present study was conducted during the kharif (monsoon) season of 2017 and the rabi (winter) season of 2017-2018 at the Research Farm of the College of Agriculture, Orissa University of Agriculture and Technology in Bhubaneswar. The focus was on the infestation of the Gundhi bug in aromatic rice under varying weather conditions. The research involved staggered planting across 12 dates, from July 16, 2017, to January 1, 2018, at 15-day intervals. Three rice varieties were studied: Geetanjali, PoornaBhog, and Pusasugandh-II. However, the planting dates of October 1 and October 16 were excluded due to high sterility caused by low temperatures.

Normal agronomic practices were followed in both the experimental plots and those adopted by local farmers. To assess the population dynamics of the Gundhi bug, damaged leaves with white or transparent patches were counted, enabling the study of its correlation with weather parameters. Throughout the investigation, key weather factorsmaximum and minimum temperatures, rainfall, relative humidity, and sunshine hourswere recorded and analyzed to identify the peak periods of Gundhi bug incidence during the growth of aromatic rice. The data aimed to establish correlations between the bug population and abiotic factors, contributing to better pest management strategies in rice cultivation.

Results and Discussion

1. Population built up of Gundhi Bug

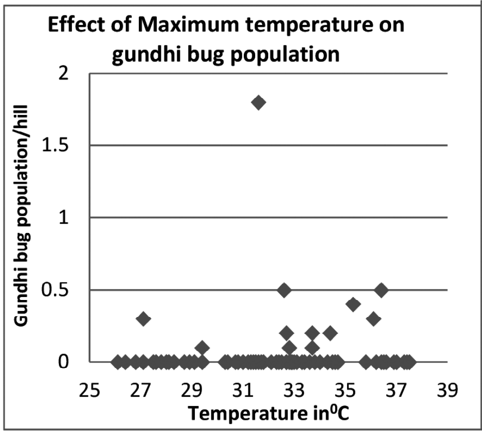
The Gundhi bug occurrence was found most of the planting date starting from 1st date (16th July) to 12th date of planting (1st January), except 16th August, 1st November, 16th November, 16th December date of planting. The number of pest per hill varied from 0.1 to 1.8 (Table 1). However, the infestation of GB was first found from 3rd week of September (SMW 38) and was continued up to 2nd week of April (SMW 45). Though the population of GB was built up from September to April, but the highest occurrence was observed during last week of November in 1st September date of transplanting, and gundhi bug was not found in November and December dates of planting.

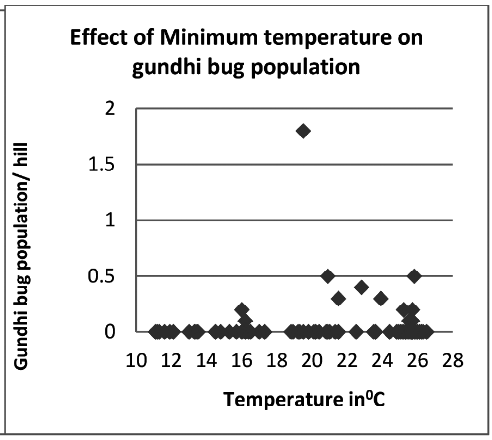
1. Table 4.13 Weekly GB Population Per Hill

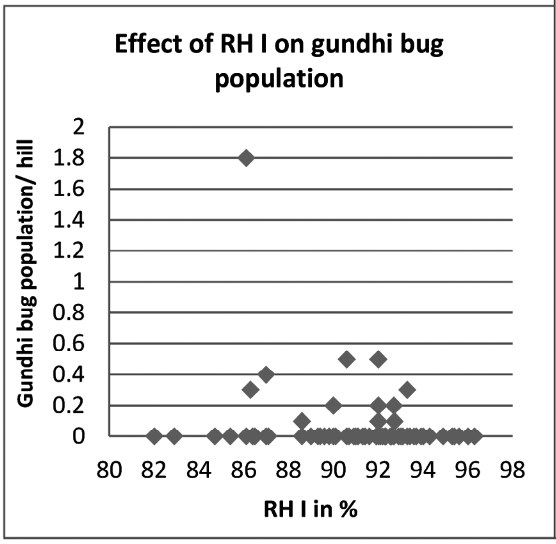
Week after planting	16-Jul	1-Aug	16-Aug	1-Sep	16-Sep	1-Nov	16-Nov	1-Dec	16-Dec	1-Jan
WK1	0	0	0	0	0	0	0	0	0	0
WK2	0	0	0	0	0	0	0	0	0	0
WK3	0	0	0	0	0	0	0	0	0	0
WK4	0	0	0	0	0	0	0	0	0	0
WK5	0	0	0	0	0	0	0	0	0	0.2
WK6	0	0	0	0	0	0	0	0	0	0
WK7	0	0	0	0	0	0	0	0	0	0
WK8	0	0.1	0	0	0	0	0	0	0	0
WK9	0.2	0.2	0	0	0.3	0	0	0	0	0
WK10	0.5	0	0	0	0.1	0	0	0	0	0
WK11	0.1	0	0	0	0	0	0	0	0	0
WK12	0	0.1	0	1.8	0	0	0	0	0	0
WK13	0	0	0	0	0	0	0	0	0	0.4
WK14	0	0	0	0	0	0	0	0	0	0.3

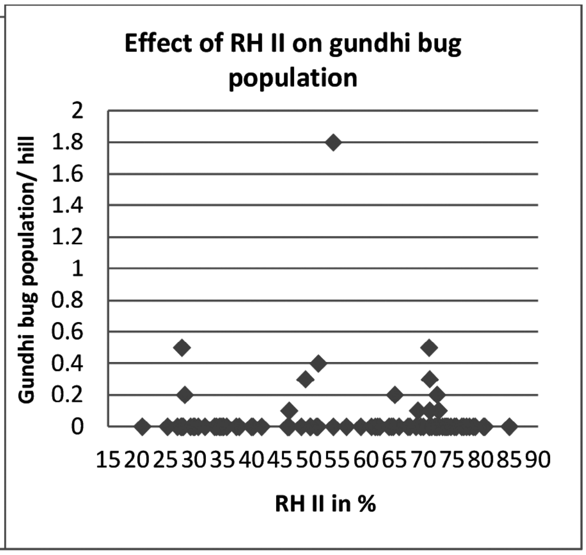
2. Favorable weather parameters for Gundhi Bug Population

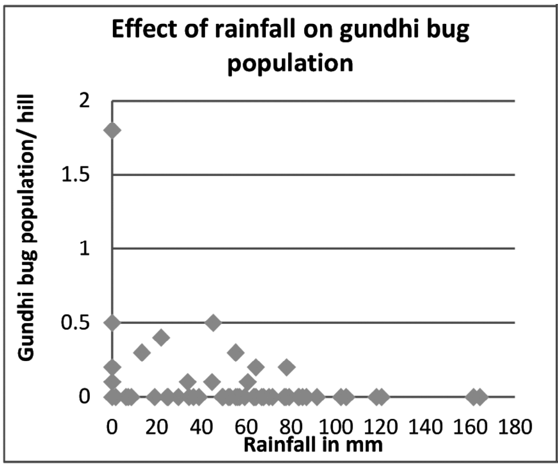
The GB population was highest when the following conditions were prevailed as maximum temperature (30-34^{0}c), minimum temperature (18-20^{0}c), morning relative humidity 85-88% and evening relative humidity 50-55%, ample sunshine hours of (9-10hr), with dry conditions found favourable

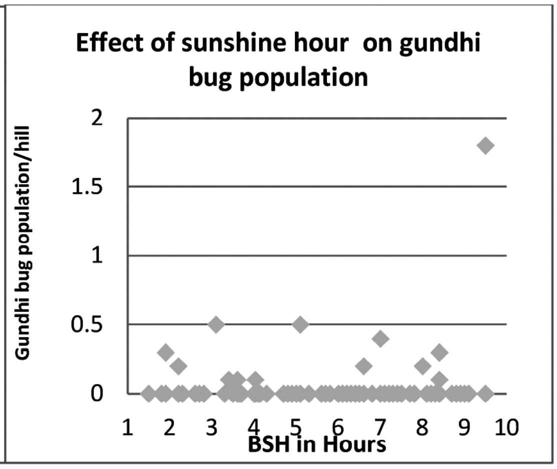












for pest population, while the GB population was found at a range of maximum temperature from (26- 37°C), minimum temperature (11- 26°C), relative humidity at morning (82-96%), relative humidity at afternoon of (20-85%), rain fall (0-160mm), with 1-10hours of sunshine (Fig 1).

3. Correlation studies of Gundhi Bug with weather parameters

The correlation between GB Population and different weather parameters revealed significant correlation only in two dates of planting viz., 1st September and 1st January out of 12 planting dates (Table 2).

The GB was negatively correlated with afternoon relative humidity with r value (-0.57) in 1st September date of planting. In 1st January date of planting GB was negatively correlated with morning relative humidity with r value (-0.66) and positively correlated with evening relative humidity and rainfall with r value (0.67) and (0.91).

Table 2. Correlation studies of population density of GB with weather parameters

WP	16th Jul	1st Aug	1st Sep	16th Sep	1st Dec	1st Jan
TX	0.18548 0.5255	-0.0652 0.8247	-0.0723 0.8059	-0.407 0.1322	0.28376 0.2697	0.22418 0.441
TN	0.06107 0.8357	-0.311 0.2791	-0.4939 0.0726	0.02275 0.9359	0.25541 0.3225	0.39285 0.1647
RH1	-0.0871 0.7672	0.04231 0.8858	-0.4638 0.0948	0.07737 0.784	-0.1332 0.6101	**-0.6683** 0.009
RH2	-0.33983 0.2345	-0.1599 0.5849	**-0.5778** 0.0304	0.19442 0.4875	-0.21 0.4174	**0.67656** 0.0079
RF	-0.21128 0.4684	-0.1433 0.625	-0.4174 0.1375	0.22076 0.4291	-0.0742 0.7771	**0.91329** <.0001
SS	-0.10939 0.7097	-0.4671 0.0921	0.52641 0.0531	-0.4147 0.1243	-0.2841 0.269	0.10269 0.7268

Summary and Conclusion

Gundhi bug was attacked the crop at reproductive stage and was at maximum occurrence during (SMW 47) followed by (SMW 37) and was aggravated by weather condition of (30-34^{0}c) maximum temperature of minimum temperature 18-20^{0}C, RH1(85-88%), RH 2(0-55%) under long hours of sunshine, GB was mostly correlated with relative humidity and rainfall.

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Importance of Millet Crops for Agricultural Sustainability in India

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Abstract

Millets are traditional cereal crops of India that play an important role in promoting agricultural sustainability under changing climatic conditions. In recent years, growing concerns related to climate change, water scarcity, soil degradation, and nutritional insecurity have renewed interest in millet-based farming systems. This review examines the significance of millet crops in enhancing environmental, economic, and social sustainability in Indian agriculture. The study is based on an extensive review of published research articles, government reports, and scholarly literature related to millet cultivation in India. Millets are well adapted to arid and semi-arid regions due to their low water requirement, drought tolerance, and ability to grow under poor soil conditions. They require minimal external inputs such as chemical fertilizers and pesticides, thereby reducing environmental pollution and production costs. Millet cultivation also improves soil health, controls soil erosion, and contributes to reduced greenhouse gas emissions. In addition to environmental benefits, millets are rich in nutrients such as dietary fiber, minerals, and antioxidants, supporting food and nutritional security. Economically, millet farming provides livelihood opportunities for small and marginal farmers and supports women's participation in agriculture. However, challenges such as low consumer awareness, weak market infrastructure, and limited policy support restrict their wider adoption. Strengthening research, policy support, market linkages, and awareness programs is essential to promote millet cultivation for sustainable agricultural development in India.

Keywords: *Agricultural sustainability, Climate resilience, Food and nutritional security, Millets, Sustainable farming*

Introduction

Indian agriculture is currently facing several challenges such as climate change, declining soil fertility, water scarcity, and nutritional insecurity. The dominance of water-intensive and high-input crops like rice and wheat have placed increasing pressure on natural resources and have reduced crop diversity. In this context, there is a growing need to promote climate-resilient and sustainable cropping systems that can support food security while protecting the environment. Millets offer a promising solution to these challenges due to their adaptability, nutritional value, and low input requirements. This highlights the grain's unique density, as a single handful of the crop can contain as many as a thousand seeds (Sukumaran *et al*., 2023).

Millets are small-seeded cereal crops belonging to the poaceae family and include important species such as finger millet, pearl millet, foxtail millet, little millet, kodo millet, proso millet, and barnyard millet. They provide a broad range of the essential vitamins and minerals required for daily body functions (Singh *et al*., 2023). These crops have been cultivated in India for centuries, particularly in arid, semi-arid, and tribal regions. Historically, millets formed a major part of the Indian food system and played a crucial role in ensuring food and nutritional security for rural communities. However, with the introduction of high-yielding varieties of rice and wheat and changes in dietary preferences, millet cultivation and consumption gradually declined over the years.

One of the most important features of millets is their ability to grow under harsh environmental conditions. Millets require significantly less water than many cereal crops such as rice and wheat and can be grown successfully under rainfed conditions. Their well developed root systems and short growing period allow them to withstand drought, irregular rainfall, and poor soil fertility. These characteristics make millets highly suitable for regions facing water scarcity and unpredictable climatic conditions. As climate change continues to affect agricultural productivity, millets have gained renewed attention as climate-resilient crops capable of providing stable yields under stress conditions.

Millet cultivation also supports sustainable farming practices by reducing dependence on chemical fertilizers and pesticides. These crops are naturally resistant to many pests and diseases and can grow with minimal external inputs. Lower chemical use helps to maintain soil health, reduce environmental pollution, and thereby, protect human health. Furthermore, millet crops improve soil structure and fertility by increasing organic matter content and microbial activity. Their dense root systems help prevent soil erosion, making them valuable for land conservation in dry and slopy areas.

2. Methodology

An extensive review of existing literature was undertaken to collect relevant research articles, reports, and scholarly publications related to millet crops and their contribution to agricultural sustainability in India. Various information sources, including peer-reviewed journals, research databases, government publications, and official reports, were systematically explored to ensure the inclusion of recent and reliable data. The collected information was carefully analyzed and synthesized to develop a comprehensive understanding of the subject.

The subsequent sections of this review examine different aspects of millet cultivation and its role in enhancing agricultural sustainability in India. This study evaluates the benefits of millet crops from environmental, economic, and social perspectives, while also addressing the challenges associated with their cultivation and the strategies required for their promotion. Through this approach, the review provides an in-depth assessment of the significance of millets in sustainable agricultural systems.

Overview of Millet Crops

Millets are small-seeded cereal crops belonging to the poaceae family, recognized for their robustness, adaptability, and high nutritional value. These crops are well known for their ability to withstand harsh environmental conditions, including drought-prone regions and soils with low fertility. Due to their short growth duration and suitability for rainfed cultivation, millets are particularly advantageous for smallholder and subsistence farmers.

Millets are highly versatile and serve multiple purposes such as human consumption, livestock feed, and industrial applications. Their gluten-free nature and low glycemic index make them suitable for individuals with dietary restrictions or lifestyle-related health concerns. Furthermore, millets are rich sources of dietary fiber, antioxidants, and essential minerals like iron, calcium, and phosphorus, contributing significantly to nutritional security.

Millets Grown in Different Regions of India

India cultivates a diverse range of millet varieties; each adapted to specific agro-climatic regions. The major millet crops grown in the country include:

Finger Millet (Ragi):

Finger millet (*Eleusine coracana*) is one of the most widely cultivated millets in India, particularly in hilly and southern regions. It is commonly used to prepare foods such as porridge, rotis, and malted products. Ragi is especially valued for its high calcium and iron content.

Pearl Millet (Bajra):

Pearl millet (*Pennisetum glaucum*) is a drought-resistant crop predominantly grown in arid and semi-arid regions of India, including Rajasthan, Gujarat, and Haryana. It serves as a staple food for many communities and is commonly used for making rotis, porridge, and animal feed.

Foxtail Millet (Kangni):

Foxtail millet (*Setaria italica*) is mainly cultivated in Andhra Pradesh, Tamil Nadu, and Karnataka. It is known for its relatively high protein content and is used in various traditional dishes such as upma, pulao, and dosa.

Little Millet (Kutki):

Little millet (*Panicum sumatrense*) is a small-seeded millet grown in dry and marginal regions of India. It is widely consumed in southern India and is used in traditional foods like idli, dosa, and pongal.

In addition to these major types, other millets such as proso millet (Chena), barnyard millet (Sanwa), and kodo millet (Kodra) are also cultivated across different regions. Each millet variety possesses unique characteristics and nutritional properties, enhancing the overall diversity and resilience of millet-based farming systems in India(Bhatt *et al.*, 2022).

Historical Significance of Millets in Indian Agriculture

Millets have a long-standing history and hold immense importance in Indian agriculture and cultural traditions. Cultivated for centuries, they once formed a major component of the country's food system. Particularly in rural, tribal, and arid regions, millets served as staple crops that ensured food and nutritional security for local populations.

Traditionally, millets were integral to indigenous farming systems due to their ability to grow under diverse agro-climatic conditions with minimal external inputs. They were consumed in various forms, including whole grains, flour, fermented products, and malted beverages. As a result, millets played a crucial role in improving dietary diversity and nutritional intake among communities.

The historical importance of millets provides a strong basis for understanding their role as sustainable crops and highlights the need for their revival to support long-term agricultural sustainability and food security in the country.

3. Environmental, Economic and Social Benefits of Millet Cultivation

Low Water Requirement, High Drought Tolerance and Climate Adaptability

Millets require substantially less water compared to water-intensive crops such as rice and sugarcane. Most millet varieties can complete their life cycle using rainfall alone i.e., without irrigation. This characteristic makes millets highly suitable for arid, semi-arid, and drought-prone regions, contributing significantly to water conservation and sustainable use of limited freshwater resources. Millets possess strong physiological and morphological traits, such as extensive root systems, which enable them to withstand prolonged dry spells and irregular rainfall. Their ability to survive under moisture stress allows farmers to achieve stable yields even during adverse climatic conditions, making millets an important crop in the context of climate change adaptation.

Minimal Requirement for Chemical Fertilizers and Pesticides

Millet production often requires fewer chemical inputs, such as fertilizers and insecticides, than other conventional cereal crops. Because millets naturally resist pests and diseases, there is less need for synthetic pesticides.

In addition, compared to other major cereal crops, millets are less susceptible to infestations of pests and diseases. This lessens the need for chemical pesticides and promotes an ecofriendly method of insect control.

Millet farming helps to mitigate the harmful effects of excessive chemical use in agriculture on the environment and human health by using fewer chemicals, which helps to prevent soil erosion and water pollution. The environmental advantages of millet production, such as their resistance to drought, efficient use of water, enhancement of soil health, preservation of biodiversity, and need for fewer chemical inputs, make them a sustainable option for agricultural practices. Promoting and emphasizing millet farming can help India's agriculture industry be more environmentally sustainable overall.

Soil Erosion Control and Land Conservation

The dense root systems and quick ground cover provided by millet crops help bind the soil and reduce erosion caused by wind and water. This is particularly important in dryland and sloping areas, where soil erosion is a major challenge. By protecting topsoil, millets contribute to long-term land sustainability.

Improvement of Soil Health and Soil Fertility

Millet cultivation enhances soil organic carbon content and improves soil structure by promoting better aeration and moisture retention. The incorporation of millet residues into the soil increases microbial activity and nutrient recycling, leading to improved soil fertility and long-term soil health.They are appropriate for cultivation on less fertile soils because of their capacity to effectively utilize the available nutrients in the soil (Joshi, 2018).

Low Carbon Footprint and Reduced Greenhouse Gas Emissions

Due to lower input requirements, minimal irrigation, and shorter growing periods, millet cultivation results in reduced energy use and lower greenhouse gas emissions. Unlike flooded rice fields, millet farming does not produce methane emissions, making it a climate-friendly cropping option.

Market Possibilities and Value Chains

As people are becoming more aware of the health benefits of millets and their role in sustainable farming, new business opportunities are developing. Millets are now being used to make many food products such as breakfast cereals, snacks, bakery items, and gluten-freefoods. This wider use of millets increases their value and helps farmers get better prices for their produce.

At the same time, efforts are being made to improve the millet supply chain and help farmers reach markets more easily. Government programs, farmer-producer organizations, and non-governmental groups are working to improve processing, storage, and marketing facilities for millets. These efforts help farmers sell their crops in bigger markets, reduce losses after harvest, and earn fair and stable incomes.

Women Empowerment

Millet farming is very helpful for empowering women. In many rural families, women are responsible for cooking and managing family food. Since millets are highly nutritious and can be prepared in many ways, they help improve the quality of food eaten at home.

Millet cultivation also gives women chances to earn income and take part in important decisions. Women are often involved in growing, processing, and selling millets. When their role in the millet value chain is recognized and supported, it helps improve their economic condition and social status.

4. Global Scenario

- Millets are cultivated globally in 131 countries.
- Africa and Asia dominate millets production followed by the European Union, America and Australia.
- India is the largest grower of millets accounting 41% of total millets production followed by Niger (11.5%) and China (692)
- India covers 83% of Asia's millets cropping area.

5. Challenges and Constraints

Lack of Awareness and Low Demand

One of the main problems in promoting millets is that many people are not aware of their benefits. For a long time, millets have been seen as less important crop than rice and wheat. With the growing use of modern and processed foods, especially in cities, the consumption of millets has decreased.

Many consumers do not know that millets are nutritious, healthy, and can be used in many dishes.

Therefore, awareness programs, advertisements, and education campaigns are needed to increase demand for millet-based foods.Promoting millet-based goods and raising customer demand can be accomplished through advertising campaigns, educational initiatives, and lobbying activities (Kondalaand Dudhagara, 2022).

Technical and Marketing Problems

Millet farmers face many difficulties due to poor facilities and weak market support. The lack of proper storage, processing units, and value-addition facilities affects the quality and shelf life of millets. Small farmers often find it hard to reach markets and do not get fair prices for their produce.

To solve these problems, better post-harvest facilities, strong supply chains, and value-addition support are required. Forming farmer groups and improving market connections can help farmers sell millets more easily and at better prices.

Limited Policy Support and Research

Another challenge is the lack of proper government support and research investment for millets. Agricultural policies usually focus more on major crops like rice and wheat, while millets receive less attention. Limited funding, subsidies, and incentives slow down the growth of millet farming.

There is also a need to protect and share traditional knowledge related to millet cultivation. Preserving local millet varieties and promoting them in suitable regions can help increase millet production.

With proper support from governments, research institutions, and other organizations, millet farming can grow in a sustainable way. These efforts will improve farmers' income, protect the environment, and create a stronger and more inclusive agricultural system.

6. Strategies for Promoting Millet Cultivation

Policy Support

Promoting millet farming requires the use of policy interventions. Millets should be given priority in government agricultural plans, and growers should get incentives and support. Input subsidies, price support measures, and insurance plans to reduce millet farming-related hazards can all fall under this category (Gowri and Shivakumar, 2020).

Policies should also put an emphasis on fostering an environment that facilitates millet production, processing, and commercialization. This entails creating infrastructure including storage spaces, processing facilities, and market connections. The incorporation of millet in government nutrition programs, school feeding programs, and public procurement activities should be emphasized in policy frameworks as well.

Research and Development

Research is important to improve millet varieties and farming techniques. The development of better millet varieties with characteristics like increased yields, disease resistance, and drought tolerance should be the main emphasis of research institutions (Govt. of India, 2014). New farming methods and technologies should also be promoted. Research can also create millet-based food products and improve processing and value addition, which can increase demand. Cooperation between research institutes, farmers, and private companies can help share knowledge and new technologies faster.

Value Chains and Market Access

Strong market connections and value chains help millet farmers earn more. Farmer groups, cooperatives, and producer organizations can help farmers sell their crops at fair prices. Better storage, processing, and packaging facilities can improve product quality and add value. Promoting millet products in local and international markets can increase demand and income for farmers.

Awareness and Knowledge Sharing

Farmers, policymakers, and agricultural experts should be educated about millet's benefits. Campaigns, workshops, and seminars can highlight their nutritional value, health benefits, and market opportunities.

Farmers should also know about government programs and support for millet farming. Traditional millet farming knowledge should be preserved and shared to protect local varieties and promote cultivation in suitable areas.

7. Conclusion

Millets offer a sustainable solution to many of the challenges faced by Indian agriculture, including climate change, water scarcity, soil degradation, and nutritional insecurity. Their low water requirement, climate resilience, and minimal need for chemical inputs make them environmentally friendly crops suitable for diverse agro-climatic conditions. In addition to improving soil health and reducing greenhouse gas emissions, millets contribute significantly to food and nutritional security. Millet cultivation also supports small and marginal farmers and promotes women's empowerment. However, wider adoption requires stronger policy support, improved research, market development, and increased consumer awareness. Promoting millet-based farming systems can play a key role in achieving long-term agricultural sustainability in India.

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Seed Certification and Quality Control Systems in Agriculture: A Comprehensive Review with Special Reference to India

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Abstract

The concept of seed certification and quality control represents an important aspect of modern agriculture. It ensures the provision of genetically pure, physiologically viable, and physically pure seeds. These systems are designed to maintain variety identity and performance by means of a well-defined procedure including seed source certification, field inspections, and laboratory tests. The current paper presents an overview of scientific literature on issues pertaining to seed certification, its principles and objectives, and its framework. Special attention will be paid to the case of India and specifically the state of West Bengal. The organizational aspects of seed certification will be considered, paying special attention to the legal base of the process, relevant organizations and bodies, and stakeholders and roles involved in the process. Also, the incorporation of national standards with international standards developed by such organizations as ISTA (International Seed Testing Association) will be evaluated. Apart from it, the paper discusses recent advances in technology and innovations that can facilitate improvements in seed certification. Some issues related to seed quality control practices and problems associated with them will also be addressed. Overall, the study emphasizes that strengthening seed certification and quality assurance systems is essential for improving crop productivity, ensuring farmer confidence, and achieving long-term agricultural sustainability and food security.

***Key words:** Seed certification, Quality control, Genetic purity, Food security, Agricultural sustainability*

Introduction

Seeds are the primary input in agriculture, and they play a critical role in the determination of productivity and the quality of crops. Therefore, any agricultural system can only be successful if there are genetically pure, healthy, and quality seeds used. Seed certification has evolved into a more systematic approach for ensuring seed quality through systematic monitoring and control (Kumar *et al.*, 2023; Olisa *et al.*, 2022).

The process of seed certification involves coordinated activities such as seed source verification, seed production supervision, field inspections, seed sampling, seed analysis in laboratories, and labeling. It helps ensure that seeds have met the required standards of varietal identification, genetic purity, germination, and health. Through such efforts, it becomes easier to avoid admixture, genetic drift, and contamination throughout the production chain. Given the widespread use of hybridized or genetically enhanced seeds, the need for proper certification to prevent genetic decay is crucial (Prasad *et al.*, 2017).

Furthermore, seed certification is critical in building the trust of farmers by ensuring that seeds perform effectively in the field. Certified seeds are generally characterized by their superior germination capability, crop uniformity, and responsiveness to agro-management practices, thus leading to improved yields and efficient use of inputs. Therefore, seed certification has become an important component of agricultural intensification programs in modern times.

At the international level, the processes involved in seed certification and testing have been standardized through the OECD (Organisation for

Economic Co-operation and Development) and the ISTA (International Seed Testing Association), making possible worldwide transactions of seeds based on quality standards (Keshavulu, 2025). In India, seeds are certified in accordance with legislative guidelines like the Seeds Act, 1966, and the Protection of Plant Varieties and Farmers' Rights Act, 2001, which collectively regulate seed quality and varietal registration.

1.1 seed Generation system in India

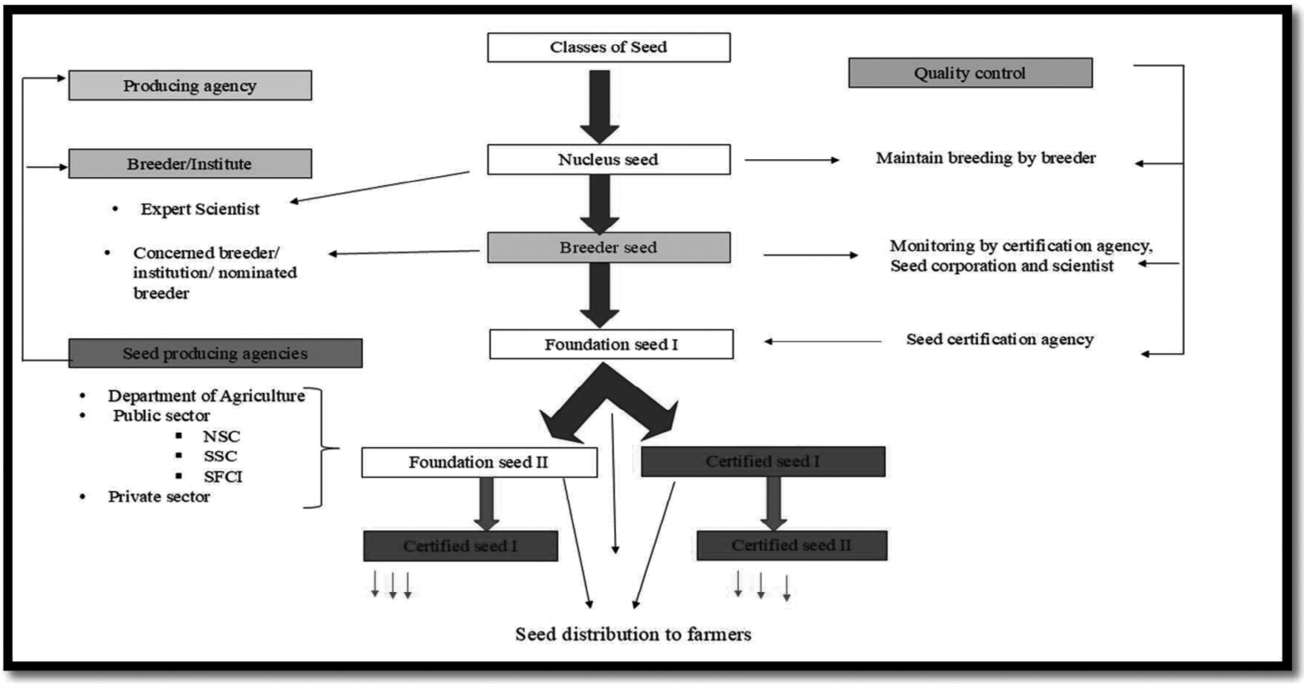

Fig 1 *Seed generation system in India*

Seed Class	Produced By	Tag Colour	Genetic Purity	Purpose
Nucleus	Original Breeder	None	100%	Initial source, small amount
Breeder	Plant Breeder/Inst.	Golden Yellow	100%	To produce Foundation seed
Foundation	Seed Agencies	White	99.5%	To produce Certified seed
Certified	Certified Agencies	Azure Blue	99%	Commercial farming

purity, physiological and physical quality, and distribution of improved varieties of crops.

One of the main goals in seed certification is to guarantee the quality of seeds through a thorough system of testing and monitoring. Modern developments in molecular genetics, seed enhancement technology, and imaging have greatly enhanced the accuracy of seed quality assessment, helping preserve genetic characteristics (McDonald, 1998).

2. Objectives of Seed Certification

The primary objective of seed certification is to provide good-quality seeds that satisfy the demands of the farmers as well as the needs of current agriculture. This involves the maintenance of genetic

Furthermore, seed certification programs have also been effective in identifying and assuring varietal purity, an increasingly vital task due to commercialization of plant breeding and protecting intellectual property rights (Cooke, 2020).

Another important objective is the reduction of the gap between experimental and farm yields. Seed quality plays a big role here, poor-quality seeds lead to low seedlings' growth rates and low production efficiency. Through their contribution to the improvement of seed vigour and germination rates, certification processes play a huge role in enhancing the performance of crops on a field level (Finch-Savage, 2016; Fan *et al.*, 2012).

Moreover, seed certification leads to the continuous supply of varieties that are stable and superior. For certification purposes, only those varieties which comply with the DUS (Distinctiveness, Uniformity, and Stability) criteria can be selected for certification purposes (Waes, 2009; Kumar *et al.*, 2023).

3. Procedural Framework of Seed Certification

Seed certification process follows a systematic structured, step-by-step procedural approach that ensures traceability and quality at each stage of seed production.

This process begins with application review of the submissions made by seed producers to the seed certification organizations. Evaluation of applications is done considering various aspects such as punctuality, varietal qualification, seed class, and conformity to set rules (Gulati *et al.*, 2013). Submission of reports of the seeding process and seed farm registration also provides adequate documentation of the seed production process, including its geographical location.

Seed source verification ensures the integrity of the seed production process. Certification is only allowed for those seeds sourced from approved seed production farms. These include breeder and foundation seeds. This way, the genetic pedigree of the seed remains intact from the beginning of seed production (ISTA, 2021).

Field inspection constitutes one of the most important components of the certification process. Inspections are conducted at multiple stages of crop growth, including pre-flowering, flowering, post-flowering, and harvest stages. These inspections aim to detect off-types, diseases, and other factors that may compromise seed quality. The frequency and timing of inspections depend on the crop type and its pollination behavior (Hussain *et al.*, 2021; Hammer *et al.*, 2006).

Quantitative assessment of genetic purity is achieved through field count methodologies, which involve systematic sampling and evaluation of plants.

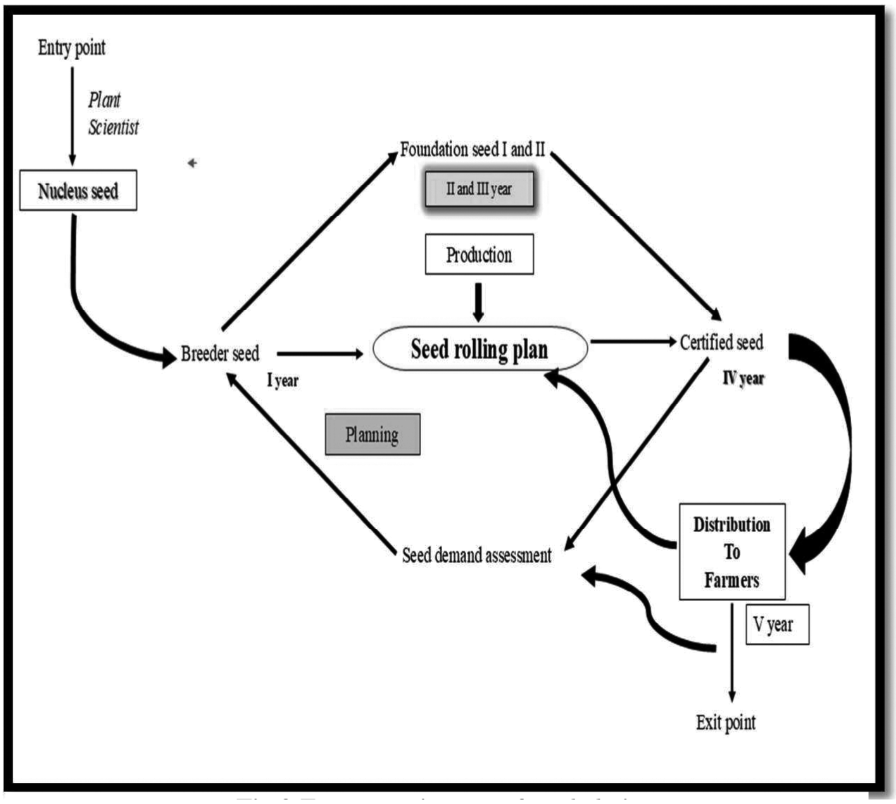

Fig 2 *Entry to exit ways of seed chain*

These methods provide objective data for determining compliance with certification standards (ICAR, 2021).

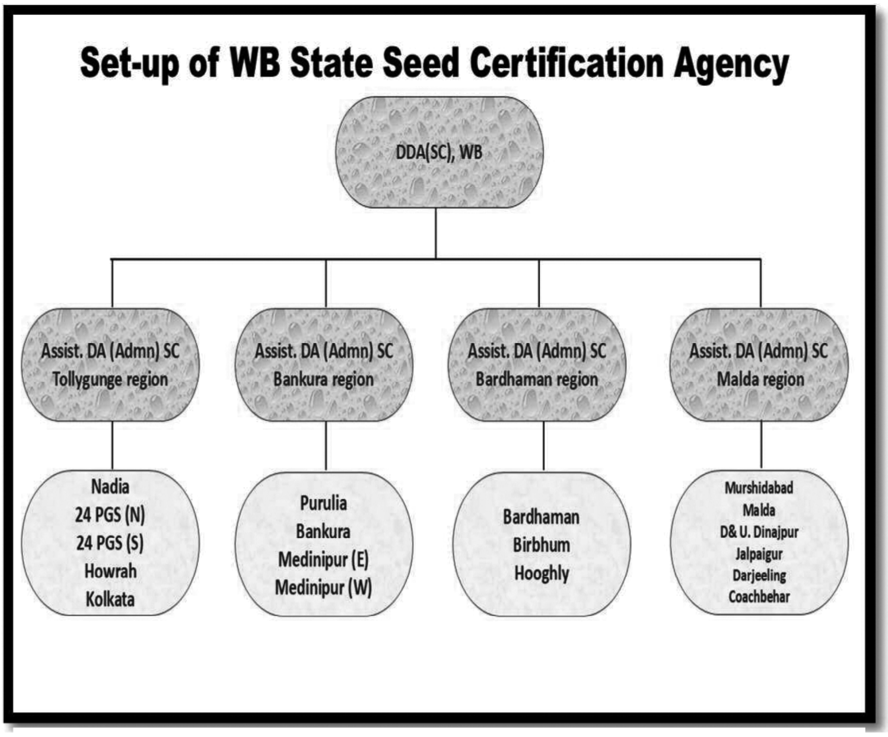

Fig 3 *Set-up of WB State Seed Certification Agency*

4. Criteria for Seed Certification

Seed certification is governed by well-defined criteria that ensure the production of high-quality seeds.

Genetic purity is the central criterion, ensuring that the seed conforms to the characteristics of the designated variety. This is evaluated through DUS testing, which assesses distinctiveness, uniformity, and stability (He et al., 2020). Physical purity is another essential parameter, requiring seeds to meet minimum thresholds for purity and limiting the presence of inert matter and contaminants (Justice & Kozlowski, 2020).

There are established standards that ensure quality in the certification process of seeds.

Genetic purity acts as one of the key criteria, ensuring that the seeds are similar in properties to designated variety. It is measured using the DUS test, which evaluates the distinctiveness, uniformity, and stability of the tested variety (He et al., 2020). Physical purity is another essential aspect of certification, which demands seeds to have certain minimum purity levels with limitations on the amount of inert and contaminant substances in the seed lot (Justice & Kozlowski, 2020).

Seed germination and vigour are critical indicators of seed performance. Certified seeds must exhibit high germination rates and strong seedling establishment, ensuring optimal crop stands under field conditions (ISTA, 2020).

Moreover, certification of seeds requires the absence of seedborne pathogens, weed seeds, and other contaminants in the tested seed lot. The above requirement can be monitored during field inspections and laboratory tests (DAC&FW, 2022).

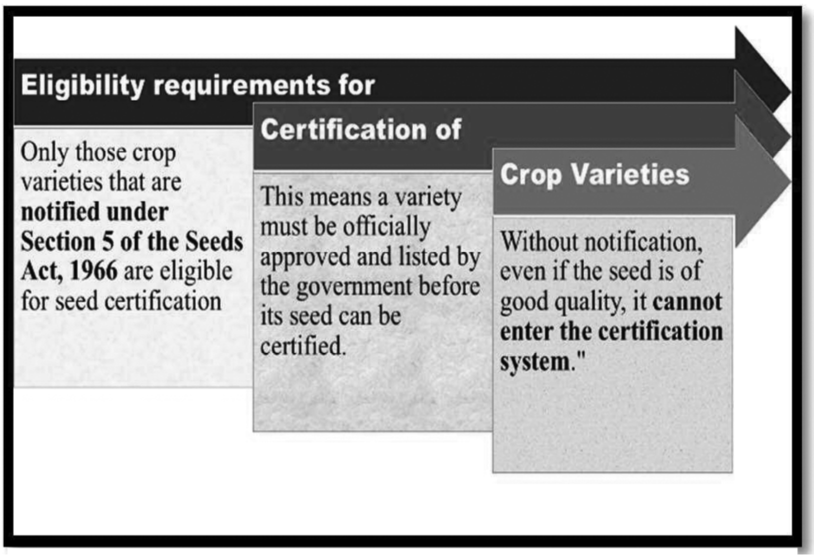

Fig 4 *Eligibility criteria of seed certification of crop varieties*

The traceability and labelling of the seed lot is another important criterion. It provides details regarding variety, purity, germination rate, and other crucial characteristics through certification tags (Copeland & McDonald, 2001).

4.1 Criteria to be fulfilled by a producer to come under S. C. Programme

Producer must have……

Seed License, Trade License, Storing and Drying Facilities, Source of Seed, Land Holding Particulars, Seed Processing Facilities, No Objection Certificate regarding pollution control, Qualified Technical Staff, Compact Area, Financial Ability, Firm Registration, Resolution Copy.

5. Seed Certification Systems in India The Indian seed certification system follows the rules set out in legislation and an elaborate institutional structure. The Seeds Act of 1966 and subsequent rules govern the certification of notified varieties. State Seed Certification Agencies (SSCAs) are mandated to implement seed certification operations in their respective jurisdictions (GOI, 2020; DAC&FW, 2022).

In West Bengal, the State Seed Certification Agency works under the Directorate of Agriculture, and the agency has regional divisions to aid the efficient implementation of seed certification activities. The stakeholders involved in seed production and certification in West Bengal include government institutions, private organizations, and cooperatives (WBSSCA, 2022).

The certification process involves multiple steps, including application submission, field inspection, seed testing, and final certification. These steps ensure that seeds meet both field and laboratory standards before being distributed to farmers.

6. Quality Control Systems in Seed Certification

A continuous process to ensure that seeds meet prescribed quality standards at every stage. like Genetic Quality, Physical Quality, Physiological Quality and Health Quality

Quality control is one of the major aspects of seed certification that helps ensure the maintenance of certain qualities and characteristics throughout the entire seed production and distribution process.

The following elements can be distinguished within the quality control process: field inspection, seed sample collection, seed testing, labeling, and post-certification monitoring. These elements serve to ensure the quality of seeds and help prevent the distribution of poor-quality seeds (FAO, 2014; GOI, 2020).

Fig 5 *Steps for Seed Certification process*

Field inspection ensures compliance with varietal standards, while seed testing involves an assessment of various important factors, including germination and moisture levels. Post-certification monitoring serves to ensure the quality of seeds at later stages of storage and distribution.

The regulatory framework supporting quality control includes the Seeds Act, 1966, Seeds Rules, 1968, and the Protection of Plant Varieties and Farmers' Rights Act, 2001. These regulations provide a legal basis for enforcing seed quality standards.

Ensuring Seed Meets Prescribed Standards:

- Quality control ensures that seeds maintain genetic purity, high germination, and freedom from contaminants.

- Only those seed lots that meet these standards are approved for sale or certification.

Monitoring During Production, Processing, and Storage:

- Quality control starts at the field stage and continues through harvesting, processing, packaging, and storage to maintain seed quality.
- Regular field inspections, lab testing, and processing checks are done to avoid mixing, while storage is monitored to prevent damage from humidity, pests, or poor handling.

7. Challenges in Seed Certification and Quality Control

Even with the presence of a systematic framework, there are various hurdles that are associated with seed certification. These are the presence of unregulated seed markets, inconsistent enforcement in different geographical regions, and the absence of adequate testing and monitoring facilities (Hassena *et al.*, 2023).

Moreover, there is a lack of awareness among farmers concerning certified seeds and their labelling, which results in the inability to use certified seeds efficiently. The institutional limitations include the availability of human resources and technical expertise, further affect the efficiency of certification agencies.

8. Emerging Trends and Future Prospects

Technological developments in the sector of biotechnology and information technology are revolutionizing seed certification processes. The use of molecular technologies like DNA fingerprinting makes variety identification and genetic purity testing more accurate. Machine learning and image technologies are also becoming increasingly popular in automatic seed quality evaluation.

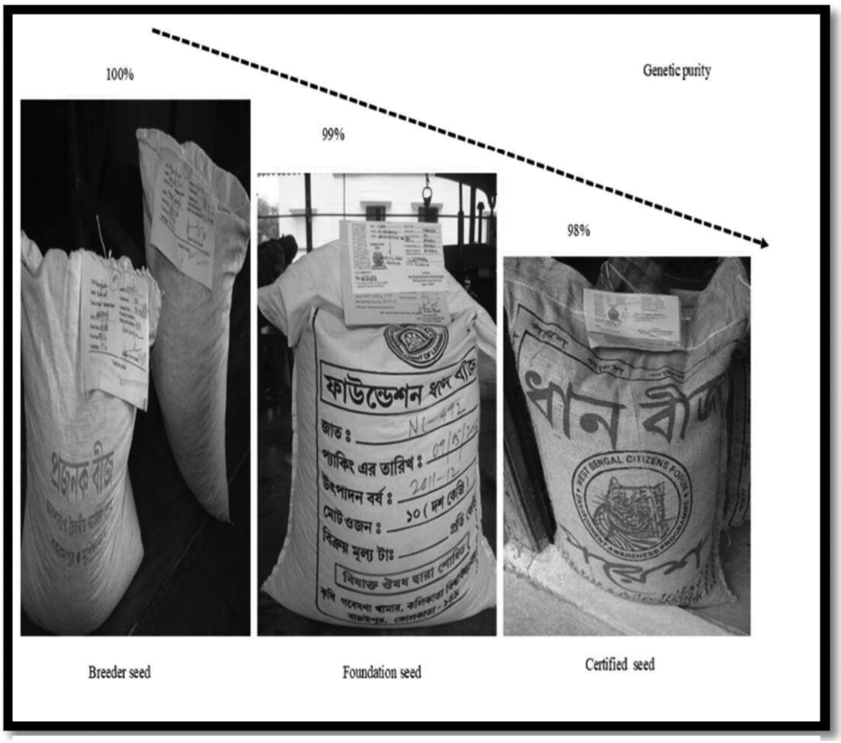

Fig 6 Genetic purity of various seed certification system

These innovations have the potential to enhance the accuracy, efficiency, and scalability of certification systems. However, their adoption requires investment in infrastructure, capacity building, and policy support.

9. Conclusion

Seed certification and quality management systems play a critical role in ensuring agricultural productivity, sustainability, and food security in agriculture. Through the maintenance of genetic integrity, the health of seeds, and the widespread adoption of advanced seed varieties, these processes make a substantial contribution to the agricultural industry.

Nevertheless, solving problems that already exist today, as well as incorporating new technologies into the system, will be crucial in boosting certification processes in the future.

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Economics of Common Paddy (Var. MTU-7029) Production and Loss Estimation by Marketing in Different Farm Size Groups of Kaimur District in Bihar - A Case Study

Surendra Kumar Singh [1], Subrata Kumar Roy [2], Amit Kumar Singh [3]

Abstract

A case study was conducted in the year 2015-16 by collection of primary and secondary data and analyzed to know the detailed coverage, production, cost, return, marked surplus etc. of marginal, small and semi medium to large farmers. We found that out of total surveyed 180 households, 157 households were involved in common/ non-fine paddy (variety MTU-7029) with 0.008 lakh acre land, 0.2 lakh qtl production with 25 qtl/acre yield. The maximum yield was achieved 2510kg paddy/acre by semi medium to large farms followed by small farms 2436kg paddy/acre. The Cost-Benefit Ratio had been calculated 1.05 for marginal farms, 1.06 for small farms and 1.02 for semi medium to large farms on the basis of total cost. According to farmers, they were losing Rs.200/ qtl by sale of their paddy to PACS due to malpractices although payments were done through bank in farmers' account directly. It was suggested that Central Govt. and State Govt. must procure the as quantity of paddy as farmers desired to sell their marketable surplus at procurement price at village level and payment must be given to farmers' account.

Keywords: *Variable and fixed cost, Gross income, Net return, Marketable surplus, Cost of production, BC ratio, Marketed Surplus, Estimation of loss etc.*

Introduction

Rice was the most important and second largest food grown after wheat in the World. It was the staple food of more than 60 percent of the world population and provided 20 percent of the world's dietary energy supply.

In Kaimur district, out of total annual cropped area 2.16 lakh ha, only paddy cultivation was 1.05 lakh ha (48.43%). Mostly non-fine paddy under Grade B / Common that was Nati / Mini Mansuri (MTU-7029) contributed 69.22% (0.72lakh ha) with production 4.29 lakh tons (76.81%) in total paddy cultivation. Mostly farmers told us during survey period that they were not getting procurement price of paddy due to malpractices. They were losing Rs.150/qtl to Rs.250/ qtl by the sale of paddy on the basis of Minimum Support Price (MSP) at different locations in the district. Govt. of India focused to increase farmers' income double by 2022 and increasing MSP was an important factor towards doubling income. Massive area and production of rice with assured irrigation as well as their seasonal marketing due to lack of go down, stress sale and forced sale for different categories of farmers (marginal, small and to large), we decided to conduct a case study to fulfill the objective regarding economics of rice and their marketing so that profitableness could be assessed for rice growers' prosperity.

Data Sources and Methodology

Primary and secondary data were collected to achieve the objectives. Primary data were collected from sampled farmers interviewing them personally by the researcher with pre-tested/ pre-structured schedules. Primary data were collected from the sample households during the crop year (2015-2016). In addition to sampled farmers, 31 famers of 11 villages

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of 6 blocks, 12 Assistant Technical Managers (ATM), Block Technical Managers (BTM), Agriculture Coordinators and three Kisan Salahkars were also personally interviewed by researcher. Two Agriculture Coordinators and three Kisan Salahkars helped to researcher in primary data collection also from different villages. Secondary data were obtained from District Statistics Office Kaimur (Bhabua), District Agriculture Office, Kaimur, District Cooperative Office Kaimur, District Industrial Centre (DIC) Kaimur, selected Block Officials and Panchayats. Different data and information were collected /used from different books, magazines, bulletins and journals as well as web sites. Secondary data were used through published in Department of agriculture, Govt. of Bihar and Agricultural Statistics – At a glance, Govt. of India also. At the first stage of sampling two sub-divisions of Kaimur District i.e., Bhabua and Mohania were selected purposively for this study due to massive cultivation of paddy. At the second stage C.D. blocks lying in the selected sub-division were enlisted in respect of area under rice. Thereafter out of 11 blocks (6 block- Bhabua, Bhagwanpur, Rampur, Chainpur, Chand and Adhaura under Bhabua Sub-Division as well as 5 block - Mohania, Kudra, Durgawati, Ramgarh and Nuaon) in the district, 50 percent block were taken in the sample purposively for this study on the basis of greater area coverage under rice. Three block- Bhabua, Bhagwanpur and Chainpur at Bhabua Sub-Division and three block- Mohania, Kudra and Ramgarh under Mohania Sub-Division were selected. At the third stage of sampling, the villages lying in the selected blocks were enlisted in respect of area under rice and their quantum of production. Thereafter, two villages from each selected block were taken randomly in the sample. Mokari and Betari villages at Bhabua block, Kaser and Parauti villages at Bhagwanpur, Awkhara and Damodarpur at Chainpur block, Bharkhar and Ahinaura at Mohania, Dihra and Nathopur at Kudra as well as Deohalia and Daharak villages at Ramgarh block were selected.

At the ultimate stage of sampling farmers lying in the selected villages were enlisted in respect of area under their operational holding and area coverage under rice and the farmers were stratified in accordance with their operational holding i.e., marginal up to 1 ha., small (1-2 ha) and large (Onward 2 hectares). Thereafter 15 farmers from each selected village were taken randomly in the sample for detailed survey. Those selected farmers were distributed to their population on different stratum. Over and above two sub-divisions, six C.D. Blocks, twelve villages and 180 farmers (48 marginal, 41 small and 91 large farmers) distributed on different three strata were included in the sample for detailed investigation.

Results and Discussion

Sample households (based on farm size groups) of Kaimur district

Table 1 reflected that 180 were randomly selected for study in which 91 (50.56%) farmers were large, 41 (22.78%) farmers were small and 48 (26.66%) farmers were marginal. 15 farmers were selected from each village in three farm size groups viz; large, small and marginal. In Bhabua subdivision 90 households were selected from six villages (Mokari, Betari, Kaser, Parauti, Awkhara and Damodarpur) of three blocks (Bhabua, Bhagwanpur and Chainpur) and 90 households were selected from six villages (Bharkhar, Ahinaura, Dihra, Nathopur, Deohalia and Daharak) of three blocks (Mohania, Kudra and Ramgarh) in Mohania Subdivision.

Sampled village wise area and production of non-fine paddy of sampled households

Table 2 revealed that area of non-fine rice were found in a range of 2.28 per cent at Damodarpur village to 79.76 per cent at Parauti village among sampled villages of total rice area whereas overall area of non-fine rice was 799.50 acres (57.13%) of total area 1399.61acres and balance 42.87 per cent (600.11 acre) was under fine rice. Out of 12 sampled villages, Nathopur had cultivated 0.00 per cent non - fine rice due to non availability of canal for irrigation and that was why they had adopted fine or medium fine rice with medium duration by irrigation with bore well. Overall 68.51 per cent (19950.80 qtl) production of non- fine rice was achieved in total production 29123.75qtls. Maximum production of non - fine rice 3287.19 qtl was achieved by Dihra village followed by Daharak village 2653.60 qtl.

TABLE 1. Selected Sampled villages and households (based on farm size groups)

S.No	Village Name	Households(nos) Large	Small	Marginal	Total	Block Name	Sub division
1	Mokari	08	05	02	15	Bhabua	Bhabua
2	Betari	12	01	02	15	Bhabua	Bhabua
3	Kaser	06	03	06	15	Bhagwanpur	Bhabua
4	Parauti	04	05	06	15	Bhagwanpur	Bhabua
5	Awkhara	00	02	13	15	Chainpur	Bhabua
6	Damodarpur	07	06	02	15	Chainpur	Bhabua
	Total	**37**	**22**	**31**	**90**	**03**	**01**
7	Bharkhar	10	04	01	15	Mohania	Mohania
8	Ahinaura	10	03	02	15	Mohania	Mohania
9	Dihra	14	01	00	15	Kudra	Mohania
10	Nathopur	08	06	01	15	Kudra	Mohania
11	Daharak	05	03	07	15	Ramgarh	Mohania
12	Deohaliya	07	02	06	15	Ramgarh	Mohania
	Total	**54**	**19**	**17**	**90**	**03**	**01**
	Grand total	**91**	**41**	**48**	**180**	**06**	**02**

Source - Households' survey (analysed primary data)

TABLE 2. Village wise area and production of non - fine paddy (MTU-7029) of sampled households

S. No	Name of the villages	Paddy area (acre) Total	Non- fine paddy (MTU-7029)	Percentage area of (MTU-7029) in total paddy area	Paddy production (qtl.) Total	Non- fine paddy	Percentage production of (MTU- 7029) in total paddy production
1.	Awkhara	23.50	0.00	0.00	335.75	0.00	0.00
2.	Damodarpur	43.96	1.00	2.28	483.60	20.00	4.14
3.	Mokari	141.00	39.00	27.66	2215.72	960.00	43.33
4.	Betari	155.55	59.00	37.93	2845.38	1398.00	49.44
5.	Nathopur	95.60	54.45	56.96	2014.21	1355.81	67.32
6.	Bharkhar	180.00	105.50	58.61	3676.90	2321.00	63.13
7.	Deohalia	149.60	89.00	59.49	3162.44	2189.40	69.23
8.	Dihra	176.50	115.80	65.61	4319.09	3287.19	76.11
9.	Ahinaura	117.25	88.00	75.06	2909.63	2310	79.39
10.	Kaser	99.25	74.75	75.32	2254.00	1869.00	82.92
11.	Daharak	134.65	107.00	79.47	3090.93	2653.60	85.85
12.	Parauti	82.75	66.00	79.76	1816.10	1586.80	87.35
	Total	**1399.61**	**799.50**	**57.13**	**29123.75**	**19950.80**	**68.51**

Source - Analyzed primary data
Note - Non- fine paddy cultivated area (%) wise village name had been arranged in ascending order

Production and income status of non-fine paddy on sample farm size groups

The data presented in Table 3 revealed that out of 180 sampled households, 157 households had cultivated non-fine paddy and generated income Rs (lakh) 231.60 from 19950.80 qtls production with productivity 24.95 qtl/acre on sampled farms. Tiwari, S.K. and Singh, P.K (2015) also founded that the yield of paddy variety (MTU-7029) was 70qtl/ha to 75qtl/ha on sampled farmers' farms at Nokha block of Rohtas district in Bihar. Two varieties were cultivated MTU-7029 (Nati Mansur) and Swarna sub-1 under non-fine paddy varieties in study area. Swarna sub-1 had been cultivated by six large farmers only with 6.56 per cent coverage area and mostly 93.44 per cent paddy area were covered by MTU-7029 (Nati Mansuri). The percentage share of large farm size group in area, production and income were found 86.68, 87.31 and 87.48 respectively followed by small farm size group 8.07 per cent in area, 7.87 per cent in production and 7.78 per cent income. Highest productivity 25.13qtl/acre and market rate Rs 1163.22/ qtl were achieved by large farm size group followed by small farm size group productivity 24.36 qtl/acre with Rs 1147.16/qtl market rate. Per household per acre income was found more in large farm size group that was Rs 29245.59 followed by small farm size group Rs 27940.91 due to better productivity and market rate.

Production, Consumption, and Marketed surplus of Non Fine Paddy on sample farm-size groups

Table 4 revealed that out of total produced non-fine paddy 19950.80 qtls, highest share 87.31 per cent was from large farm size group followed by small farm size group 7.87 per cent. Sampled large farmers did not consume non- fine rice at all. Maximum 75.41 per cent non-fine paddy was consumed by marginal farmers followed by small farmers 24.59 per cent of total non-fine paddy consumption. 86.72 percent non-fine paddy was found marketed surplus in large farms size group followed by small farm size group 8.26 per cent of total marketed surplus of non-fine paddy 18952.37 qtls.

Per acre costs, returns and cost of production in Rice cultivation on sample farms

Variety- MTU-7029 (Nati / Mini Mansuri)

Table 5 revealed the per acre variable cost, fixed cost and total cost/cost of cultivation of fine rice variety (**Nati/Mini Mansuri**) in different size groups of farms viz; marginal, small and large. It included yield (in kg.), gross value of yield (Rs.), return (profit) over variable and total cost. Table 9 also covered the benefit-cost ratio and cost of production. Maximum variable cost was found on human labor Rs.6650, Rs.6775 and Rs.5700 in marginal farm, small farm and large farm respectively. Yield was achieved maximum 2510kg. on large farm followed by small farm 2436kg. Maximum cost of cultivation/production was calculated Rs.31260 for large farm followed by small farm Rs.28623. Return over variable costs were Rs.11915, Rs.13532 and Rs.15221 in marginal farm, small farm and large farm respectively whereas return over total costs were found maximum Rs.1818 in small farm followed by Rs.1441 in marginal farm. Costs of production on the basis of total cost were found Rs.11.82 per kg., Rs.11.75 per kg. and Rs.12.45 per kg in marginal, small and large farm respectively whereas gross return was highest in large farm Rs.31917 followed by Rs.30441 in small farm in the production of paddy Variety- Mini Mansuri. Cost-Benefit Ratio had been calculated 1.05 in marginal, 1.06 in small and 1.02 in large on the basis of total cost.

Procurement was done by Govt., millers/wholesalers and other agencies. Declared MSP Grade-B/Common, supported coarse rice like- MTU7029 (Nati/Mini Mansuri). Prevailed market rate at that time was found less (Rs.1100-1200/qtl.) than procurement price (Rs.1410/qtl). Govt. did not procure the quantity as much as farmers wanted. Share of procurement price was 90% by Central Govt. and 10% by State Govt. Mostly farmers noticed that they got Rs1200-1250/qtl instead of Rs1410/qtl. Bihar Govt. procured Nati/Mini Mansuri through PACS (Primary Agricultural Credit Society) in Panchayat level and through Vyapar Mandal on block level in the Year 2015-16.

TABLE 3. Production and income status of Non-Fine Paddy on sample farm size groups

Particulars	Non - Fine Paddy			Overall (Non Fine Paddy)
	Marginal	Small	Large	
1. Total area (acre.)	42.00 (5.25)	64.50 (8.07)	693.00 (86.68)	799.50 (100.00)
2. Total production (qtl.)	962.50 (4.82)	1571.00 (7.87)	17417.30 (87.31)	19950.80 (100.00)
3. Total income (Rs.)	10,96,675 (4.74)	18,02,189 (7.78)	2,02,60,176 (87.48)	2,31,59,040 (100.00)
4. Productivity (qtl./acre)	22.92	24.36	25.13	24.95
5. Surveyed households	48	41	91	180
6. No. of household involved in production	25	23	69	157
7. Avg. production per household (qtl), involved in production	38.50	68.30	252.42	127.08
8. Avg. income per household (Rs), involved in production	43,8677	8,356.04	2,93,625.74	1,47,509.81
9. Avg. income per acre	26,111.31	27,940.91	29,235.46	28,966.90
10. Avg. area (acre.) per household(qtl.) based on involved in production	1.68	2.80	10.04	5.09
11. Avg. income per household per acre (Rs.) based on involved in production	26,111.31	27,940.91	29,235.46	28,966.90
12. Achieved market rate (Rs./qtl.)	1,139.40	1,147.16	1,163.22	1,160.81

Source - Analyzed primary data *Figures in parenthesis showed percentage*

TABLE 4. Production, Consumption, and Marketed surplus of Non -fine paddy on sample farm-size groups

Farm-size groups	Production		Food consumption		Payment for wage		Marketed surplus	
	Non - fine paddy (qtl.)	Percen-tage	Non - fine paddy (qtl.)	Percen-tage	Non - fine paddy (qtl.)	Percen-tage	Non -fine paddy (qtl.)	Percen-tage
Marginal	962.50	4.82	9.20	75.41	1.50	0.16	951.80	5.02
Small	1571.00	7.87	3.00	24.59	2.23	0.23	1565.77	8.26
Large	17417.30	87.31	0.00	0.00	982.50	99.61	16434.80	86.72
Total	19950.80	100.00	12.20	100.00	956.23	100.00	18952.37	100.00

Source - Analyzed primary data

Table 6 revealed that 5kg. seed, and 150kg. manures had been used on large farm to produce MTU-7029 (Nati/Mini Mansuri) by marginal farmer. Minimum Human labour 30 mandays was used by large farmers and highest by small farm 36 mandays. Costly fertilizer like DAP was used 54kg, 58kg. and 62kg. by marginal, small and large farmers respectively. Maximum quantity of nitrogenous fertilizer that was urea was used 85 kg. 90 kg. and 100 kg. in marginal, small and large farmers respectively. Per acre irrigational charge was very low

Table 5. Per acre costs, returns and cost of production in Rice cultivation (Year 2015-16) on sample farm

Variety: MTU-7029 (Nati/Mini Mansuri)

S.No	Cost Components	Marginal (Rs.)	Small (Rs.)	Large (Rs.)
I.Variable Cost				
1.	Human Labour	6650	6775	5700
	a. Family/ Owned	4650 (17.17)	4375 (15.28)	1700 (5.44)
	b. Hired	2000 (7.38)	2400 (8.38)	4000 (12.80)
2.	Seed	240 (0.89)	250 (0.87)	300 (0.95)
3.	FYM/Compost	500 (1.92)	400 (1.40)	300 (0.95)
4.	Chemical fertilizer	2341 (8.64)	2492 (8.71)	2805 (8.97)
	a. DAP	1296	1334	1488
	b. Urea	595	630	700
	c. MOP	350	378	392
	d. Others (Micronutrients)	100	150	225
5.	Plant protection	450 (1.66)	400 (1.40)	650 (2.08)
6.	Irrigation charges	1975 (7.39)	2100 (7.34)	2085 (6..68)
7.	Machinery charges	2050 (7.67)	2087 (7.29)	2195 (7.04)
8.	Total(1-7)	14206	14504	14035
9.	Interest on working capital @8 per cent per annum for 6 month	568 (2.10)	580 (2.03)	661(2.12)
10.	Harvesting, threshing and winnowing	1800 (6.45)	1825 (6.38)	2000 (6.40)
11.	Total Variable Cost (TVC), 8-10=I	16574	16909	16696
II. Fixed cost				
12.	Depreciation	500 (1.85)	600 (2.10)	1200 (3.84)
13.	Land Revenue	14 (0.05)	14 (0.05)	14 (0.04)
14.	Rental value of land	8000 (29.63)	8000 (27.95)	8000 (25.59)
15.	Interest on fixed capital @10 per cent per annum for 6 month	1650 (6.19)	2750 (9.61)	5000 (15.99)
16.	Crop insurance(Premium charges) @ 2 per cent	350 (1.29)	350 (1.22)	350 (1.11)
17.	Total fixed cost(TFC,12-16)=II	10514	11714	14564
18.	Total cost(I+II)=11+17	27088 (100.00)	28623 (100.00)	31260 (100.00)
Output /Return				
19.	Main product(Rs./Acre)	26129	27941	29317
	Price (Rs./kg.)	11.40	11.47	11.68
	Main product(kg./Acre)	2292	2436	2510
	By product(Rs./Acre)	2400	2500	2600
	Price (Rs./kg.)	1	1	1
	By product(kg./Acre)	2400	2500	2600
20.	Gross Return (Main product + By product)	28529	30441	31917
21.	Return over variable cost	11955	13532	15221

S.No	Cost Components	Marginal (Rs.)	Small (Rs.)	Large (Rs.)
22.	Return over total cost	1441	1818	657
23.	Benefit-Cost Ratio over A. variable cost B. Total cost	1.721.05	1.801.06	1.911.02
24.	Cost of production(Rs./ kg.) over A. variable cost B. Total cost	7.2311.82	6.9411.75	6.6512.45
25.	Return from Main Product with procurement price (MSP) @1410 per qtl.	32317	36848	37991
26.	Per acre income loss ((Rs.) on the basis of main product (Procurement-Market price)	6188	6407	6074
27.	Per acre loss of income in percentage (based on main product)	23.88	22.93	20.72

Source - Primary data analysed *Figures in parenthesis shows percentage*

TABLE 6. Quantity of physical input used in cost of cultivation per acre categories wise
Variety: MTU-7029 (Nati/Mini Mansuri)

Input	Marginal	Small	Large
1.Seed (kg.)	5	5	4
2.Manures (kg.)	150	125	125
3.Fertilizers (kg.)			
a. Urea	85	90	100
b. DAP	54	58	62
c. MOP	25	27	28
d. Macro and Micronutrients	3	3	4
4. Plant protection chemicals (Ltr/kg.)	1	1	2
5. Machinery charges (Mostly tractor, harvester, thresher and winnowing fan etc) in hrs.	3-4	4-5	5-6
6. Irrigational charges (Diesel pump / Electric motor pump) and canal (in hrs.)	10-12	10-12	10-12
7. Human labour (Man days)	35	36	30

Source- Household survey (Primary data)

Rs. 88 (Canal Department ,Bhabua, Kaimur). Farmers irrigated their paddy from tube well and other available sources with pumpset as well as electric motors when there was a delay or lack of water in canal.

Conclusion and Policy Implications

All farm size group (marginal, small and large) farmers lost approx. Rs. thirty eight Lakh by the sale their non- fine paddy (MTU-7029) 18952.37 qtl and purchased by Govt.(PACS) and private agencies – rice millers, wholesalers and retailers due to Rs. 200/ qtl. loss. It was suggested that Central Govt. and State Govt. must procure as much as the quantity of paddy as farmers desire to sell their marketable surplus at procurement price and payment must be given to farmers' account in bank under DBT. Separate Payment Cell would be established in Central and State department. Detailed of procurement would reached from village to Central/State Govt. Neither middleman nor panchayat/block/district level authority would be involved in that context. More awareness programmes must be conducted among farmers against malpractices and corruptions during procurement and payment of paddy.

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India's New "Rice King" Status: A Historic Milestone Or A Water-Guzzling Trap?

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Abstract

India has recently emerged as the world's leading rice producer, surpassing China in total harvest volume. However, this historic agronomic milestone conceals a profound ecological crisis driven by the hyper-extraction of groundwater and resource intensive cultivation practices to stabilize global food markets. Furthermore, traditional continuous flooding techniques trigger a severe climate feedback loop; submerged paddies generate immense methane emissions, while the energy demanded for deeper groundwater pumping significantly inflates the nation's carbon footprint. To escape this water-climate trap, this article argues that the next agricultural pattern must prioritize resource use efficiency over sheer caloric output. Critical interventions include scaling water saving methodologies like Direct Seeded Rice (DSR), diversifying cropping systems with climate resilient "nutri-cereals" such as millets, and fundamentally overhauling policy frameworks to incentivize water conservation rather than subsidizing its extraction. Ultimately, India's agricultural success must be redefined from maximizing output to optimizing resource efficiency and ecological resilience, ensuring the nation does not liquidate its hydrological heritage to serve as the world's breadbasket.

Keywords : *Agricultural sustainability, Crop diversification, Groundwater depletion, Methane emissions, Rice production, Virtual water trade, Water footprint.*

Introduction

Although rice is the staple food for almost half of the global population, 90% of the world's rice-producing area still lies in Asia (Prasad *et al*., 2012). History dictates that South and Southeast Asia have played a foundational role in the evolution of rice, spanning from its initial origins to modern scale of mass production (Solheim, 1972; Chang, 1976; Ramiah, 1937; Roschevitz, 1931).Tracing back to approximately 2500 B.C., grain samples recovered from the Mohenjo-Daro excavation site in contemporary Pakistan establish ancient India as one of the earliest known regions to cultivate *Oryza sativa* (Khush, 2000; Andrus &Mohammed, 1958). Accounting for nearly half of the world's genetic diversity of this crop, India is home to approximately 60,000 of the 123,000 globally recognized rice varieties (ICAR-National Rice Research Institute, 2022).

This heavy reliance on a single continent leaves global food security and supply chains uniquely vulnerable to regional climatic aberrations and economic shifts, a volatile landscape where India has recently emerged as the central player.Whether measured by the total land area dedicated to rice or its overall production yield, India commands a massive presence on the global stage.

Despite long holding the global top spot for total acreage dedicated to rice cultivation, India historically trailed behind China in overall production volume(United States Department of Agriculture [USDA], 2025).However, driven by continuous agricultural advancements and high-yielding crop varieties, India has closed the yield gap and climbed to the summit as the world's absolute top rice producer by officially overtaking China in total harvest volume(India Today, 2025; The Times of India, 2026). This remarkable ascent in early 2026 not only solidifies India's new title as the undisputed "Rice King" but also fundamentally reshapes the global agricultural hierarchy, contributing roughly 28% of global output alone (USDA World Agricultural Outlook Board [WAOB], 2026).

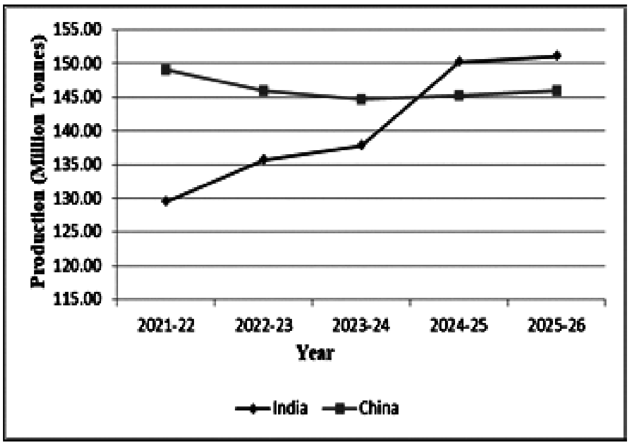

Figure 1: Total rice production trends of India and China(Source- Department of Agriculture & Farmers Welfare, 2026; USDA Foreign Agricultural Service [FAS], 2025, 2026)

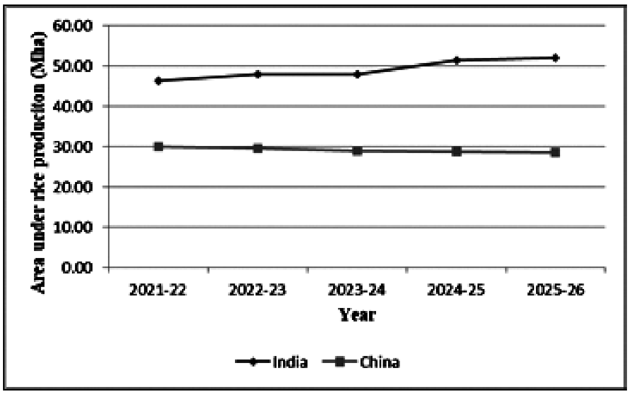

Figure 2: Rice acreage trends in India and China (USDA WAOB, 2026; USDA FAS, 2025, 2026)

While India's undisputed dominance in global rice production is a monumental geopolitical and agricultural achievement, rice remains one of the highest water-feeding crops, meaning this top-ranking status comes with a severe ecological price tag (Singh *et al.*, 2023). Currently India harvests over 145 million tonnes, generating a massive exportable surplus of nearly 30 million tonnes, as its total milled rice production continues to vastly outpace its domestic consumption needs of approximately 115 to 118 million tonnes(USDA FAS, 2026). It implies that we are heavily engaging in "**virtual water**" trade, effectively subsidizing global food security while our local aquifers rapidly drain. This irony forces us to confront a critical question: is this record-breaking production truly beneficial for our economy, or is it an ecological trap where we are feeding the world at the cost of our own future thirst (Sharma & Kumar, 2024)?

The Green Gold Rush (The Economic "Milestone")

The Global Feeder : India's ascent to the apex of global rice production is not merely a domestic win; it is the keystone of international food security along with an important tool of India's foreign policy.By consistently exporting roughly 40% of the world's rice throughout 172 countries over the last decade, India acts as a crucial shock absorber for volatile global markets (USDA WOAB,2026; India Today, 2025). Nations across Sub-Saharan Africa such as Senegal, Benin, and Côte d'Ivoire as well as neighbouring Asian countries rely heavily on Indian shipments of non-basmati and broken varieties to keep their domestic food inflation in check and stave off hunger. The extent of this reliance becomes starkly evident whenever New Delhi implements export restrictions to cool domestic prices; a localized policy shift in India immediately triggers price spikes and food access crises across the Global South (Glauber & Abdullah, 2023). In this context, India's "green gold" is practically a global public good.

The Economics of Farmer Preference : At the grassroots level, however, this massive output is not driven by a philanthropic desire to feed the world, but by rational agricultural economics. For the Indian farmer, paddy is less of a crop and more of an economic shield. The architecture of India's agricultural policy, heavily anchored by the Minimum Support Price (MSP) and robust state-backed public procurement systems, heavily incentivizes rice cultivation over almost anything else. Compared to the severe price volatility and fragile market linkages associated with pulses, millets, or oilseeds, paddy offers a guaranteed buyer and a highly predictable income (Kaur & Singh, 2024). This entrenched supply chain creates a formidable behavioural loop: farmers continue to plant water-guzzling paddy simply because it remains the safest, most de-risked financial bet available to them, regardless of whether their local geography is suited for it.

The China Comparison (Volume vs. Efficiency) : Yet, celebrating this absolute output masks a critical inefficiency when placed on a comparative scale. While India recently overtook China to become the world's largest producer of rice by sheer volume, it still lags behind in per-hectare yield. China manages to produce a nearly identical volume of milled rice(around 145 million tonnes) but achieves this on a fraction of the land. Where India dedicates upwards of 45 to 50 million hectares to achieve its record harvests, China utilizes less than 30 million hectares, relying instead on exceptionally high-yielding hybrid varieties and hyper-intensive agronomic practices (USDA FAS, 2024).

In the years immediately following independence (1950–51), Indian paddy fields yielded a mere 668 kg of rice per hectare. The landscape shifted dramatically in the mid-1970s; propelled by the Green Revolution's introduction of dwarf varieties and chemical fertilizers, yields nearly doubled to 1,235 kg/ha. This steady upward trajectory continued through the turn of the century (reaching 1,901 kg/ha in 2000–01) and climbed to 2,809 kg/ha by 2021–22 (Ministry of Agriculture and Farmers Welfare [MoAFW], 2023).Recent forecasts indicate this momentum is holding strong, with projections suggesting India's average yield could reach an impressive 4,390 kg/ha by the 2025–26 season (USDA FAS, 2025). Yet, a sobering reality is Indian productivity still lags behind the global average. The ultimate benchmark of efficiency remains China, which routinely harvests roughly 7,100 kg per hectare (USDA FAS, 2026).

This stark contrast in land to yield ratios shifts the narrative away from a simple celebration of volume. India has undoubtedly conquered the metric of total mass, but the Chinese model highlights a huge gap in resource efficiency, setting the stage for necessary modifications regarding the ecological cost of India's current trajectory.While matching this Chinese milestone would be a monumental triumph for Indian agronomy, it presents a exhaustive scenario because paddy is inherently water-intensive and chasing hyper-yields without drastically overhauling our irrigation technologies could severely aggravate the country's ongoing groundwater crisis.

The 4,000-Litre Price Tag

The Water Footprint : Rice cultivation is extraordinarily water-intensive.The staggering volume of India's rice production obscures a structural inefficiency: traditional flood irrigation, the dominant method in India's rice systems, leads to high evaporation and percolation losses.Rice demands the highest IW/CPE ratio among major crops, intrinsically resulting in the lowest water use efficiency (Bouman *et al*., 2007). In the semi-arid climates where much of India's commercial cultivation is concentrated, producing just a single kilogram of milled rice demands an astronomical 3,000 to 5,000 litres of freshwater (Sharma *et al*., 2025). Empirical studies further show significant regional variation; for instance, water footprints in parts of Punjab exceed 3,000 litres per kilogram for certain rice varieties, reinforcing the crop's classification as a "water-guzzler" (Kaur & Rampal, 2024).Out of the global rice area, 45% area comes under rainfed lowland ecosystem whereas flood irrigated on bunded fields covers 44%. The remaining 11% is covered by rainfed upland rice ecosystems (Prasad *et al*., 2012). In a country already categorized among the world's most water-stressed, such consumption patterns place immense pressure on finite freshwater resources (Ercin& Hoekstra, 2012).

The "Virtual Water" Trade : This localized water consumption scales into a massive geopolitical absurdity through the mechanism of "virtual water" trade. Virtual water refers to the hidden volume of freshwater embedded in the production of traded agricultural commodities. When India proudly exports upwards of 20 million tonnes of rice annually, it is not merely shipping grain; it is effectively hemorrhaging trillions of litres of its domestic freshwater reserves. In essence, India, a nation grappling with severe, looming water scarcity is continuously exporting its most precious natural resource to stabilize the food security of countries that are often far more water-rich than itself (Nishad & Kumar, 2022). The export revenue captured on the national balance sheet is

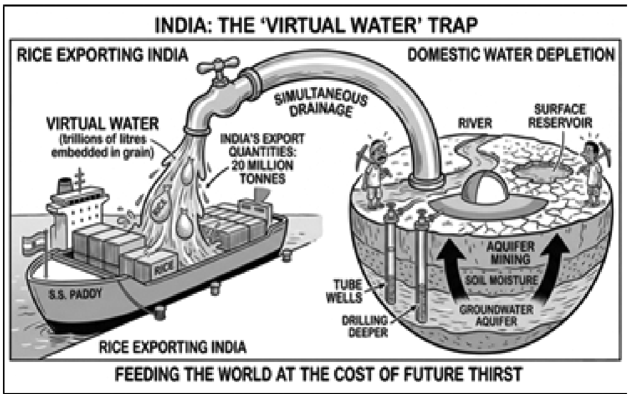

Figure 3 : Export of Ground Water Resources in the Form of Rice

entirely disproportionate to the permanent hydrological deficit left behind in the soil.

Ground Zero: The Tube Well Race- The consequences of this crisis are most visible in the agricultural heartlands of Punjab and Haryana, where the Green Revolution entrenched rice-wheat mono-cropping systems.Here, because the natural monsoon rainfall is woefully inadequate to sustain continuous paddy flooding, groundwater extraction has reached critical levels. Farmers increasingly rely on tube wells, leading to what is often described as a "tube well race". Over time, the depth required to access water has increased dramatically, from around 30 feet in earlier decades to over 200 feet (and in some areas 300 to 400+ feet) today (Reuters, 2025). Submersible pumps are now routinely bored down to 400 feet or deeper (Kishore, 2025). Driven by the lure of the Minimum Support Price and enabled by heavily subsidized electricity, agriculture here has shifted from harvesting surface water to actively mining "fossil water" deep, ancient aquifer reserves that recharge extremely slowly, often over centuries and will not naturally replenish in our lifetimes. Empirical research indicates thatpolicy-driven rice procurement accounts for a significant portion of this depletion (Dangar & Mishra, 2024). We are, quite literally, liquidating our geological heritage to sustain a temporary agricultural boom.

The Dual Climate Burden

When we think of agricultural water scarcity simply as "running out of water," we miss the broader, far more dangerous picture. The rice economy does not just strain water resources moreover it quietly intensifies climate change, creating a feedback loop that traps farmers in an increasingly fragile system.

The Methane Factory: A flooded paddy field may look calm on the surface with shallow water sustaining young rice shoots and reflecting the sky, but beneath that still water layer exists an entirely different submerged ecosystem, a distinct microbial biome functioning as a highly efficient methane factory. When the rice fields remain submerged for weeks, the soil gets choked off from oxygen. This creates the perfect anaerobic condition, ideal for methane-producing microbes. These microorganisms break down organic matter and release methane (CH„), a greenhouse gas far more potent than carbon dioxide in the short term.Studies show that continuous flooding maximizes methane emissions, while controlled irrigation can significantly reduce them (Han*et. al.*, 2024).

Given that methane packs a warming punch over 25 times stronger than carbon dioxide over a 100-year timescale, the impact of this microscopic process is staggering. Flooded rice systems are among the largest agricultural sources of methane globally (Arenas-Calle *et al.*, 2024). Recent global inventories indicate that rice cultivation contributes about 10–15% of global methane emissions, generating more than 39 teragrams (million metric tonnes) annually (Pazhanivelan *et al.*, 2024; Qian *et al.*, 2023).

So the same water that sustains rice is also the trigger for its climate footprint.By relying heavily on continuous flooding techniques, we are essentially trading atmospheric stability for caloric security

The Vicious Cycle: The crisis extends beyond just methane; as a shifting climate forces farmers to pump deeper for groundwater, the massive energy required to run those pumps further adds another heavy layer of greenhouse gas emissions. It acts as a relentless feedback loop. The regions like South Asia, where rice production is heavily dependent on monsoon rain, acts as ground zero.

As global temperatures rise, weather patterns fracture. The monsoon season, once a reliable clockwork of agricultural timing, has become deeply erratic. Prolonged dry spells are now routinely punctuated by flash floods rather than steady, soaking rains. Because farmers can no longer rely on predictable surface water, they are forced to seek alternatives. To keep their crops alive, the only rational response is to drill deeper and pump more groundwater. Pulling billions of cubic litres of water from deep, depleting aquifers requires a significant amount of energy. In India alone, an estimated 20 to 25 million agricultural tube wells operate extensively during dry spells, powered largely by an electricity grid that remains overwhelmingly dependent on coal.

Research indicates that groundwater pumping for agriculture contributes between 32 and 131 million tonnes of carbon emissions annually in India, accounting for up to 7% of the nation's total carbon footprint (Kaur *et al.*, 2018). Beyond these direct emissions, there exists an additional geochemical pathway that further amplifies the carbon burden. The extraction of deep groundwater causes sudden drop in hydrostatic pressure, triggering the precipitation of dissolved bicarbonates and resulting in the release of carbon dioxide into the atmosphere.

This feedback loop is not theoretical. Research on South Asia shows rising atmospheric methane concentrations alongside emissions from both agriculture and coal-based energy systems, highlighting how these sectors reinforce each other (Dangeti *et al.*, 2024).

Escaping the Trap

Diagnosing a systemic failure must be followed by intervention strategy. If the Green Revolution was defined by maximizing caloric yield regardless of the environmental cost, the next agricultural revolution must

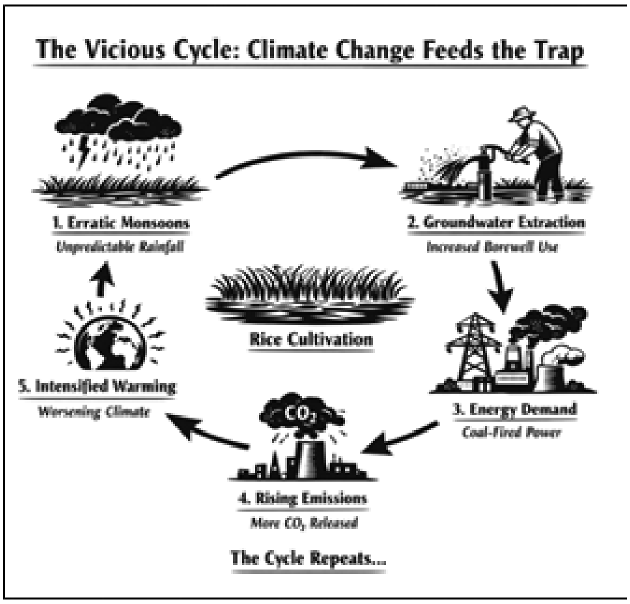

Figure 4 : Severe Water-Climate Feedback Loop

be defined by resource use efficiency. Escaping this water-climate cycle requires a fundamental shift in how judiciously the inputs like water, fertilizers and other agronomic practices aligned.

Insisting on More Crop per Drop : The most immediate intervention is to change how we cultivate our most water-intensive staple. Traditional rice farming relies heavily on puddling and continuous flooding, a practice where massive volumes of water are lost to evaporation and deep percolation. To achieve "more crop per drop," agronomists are pushing for the rapid scaling of alternative methodologies like Direct Seeded Rice (DSR) and the System of Rice Intensification (SRI) as they rely on controlled irrigation, soil aeration, and precise input use.

DSR bypasses the water-heavy nursery and puddling phases entirely by sowing seeds directly into the field, much like other crops. SRI takes a different approach, increased plant spacing (25x25 cm) and utilizing alternate wetting and drying (AWD) to keep soils moist rather than perpetually submerged (Dass *et al.*, 2015). Recent field evaluations demonstrate that transitioning to DSR and AWD can reduce irrigation water use by 20% to 30%, while simultaneously cutting methane emissions by up to 50%, all without a statistically significant penalty to crop yields (Mishra *et al*., 2021). We can maintain the food supply; we simply have to reduce using water intensive cultivation practices.

Crop Diversification : Crop diversification becomes essential in large parts of India where rice is still grown despite the region being ecologically unsuitable for it. For decades, agricultural policy has heavily favoured thirsty crops, side-lining indigenous, climate-hardy crops. Millets, often referred to as "nutri-cereals" offer a compelling alternative. They are C4 plants, meaning their biological pathways are inherently more water-efficient and heat-tolerant than rice. Shifting even a fraction of current rice acreage in water-stressed regions back to these historical staples could dramatically relieve pressure on groundwater. Recent comprehensive modeling indicates that replacing just 20% of rice cultivation with millets in India's most depleted regions could reduce agricultural water demand by up to 21%, while actually increasing the iron and zinc output of the harvest (Davis *et al*., 2018).Between 2002 and 2022 alone, India lost hundreds of cubic kilometres of groundwater, much of it linked to water-intensive cropping patterns (Dangar & Mishra, 2024). Diversification, therefore, is not merely an agronomic choice but a strategic hydrological necessity.

Policy Shift- Realigning the Economics of Water : The most stubborn barrier to escaping this trap is a deeply entrenched policy failure: the rampant subsidization of groundwater extraction. For decades, India's agricultural economy has been shaped by a powerful incentive structure:

- Free or heavily subsidised electricity encourages unlimited groundwater pumping
- Minimum Support Prices (MSP) favour water-intensive crops like rice
- Risk-averse farmers rationally respond by maximising short-term output

When the power to pump costs nothing, there is absolutely no economic rationale for a farmer to invest in saving water. Governments are effectively subsidizing the exact mechanism that is bankrupting their aquifers and driving up carbon emissions. Hence, governments must transition from energy subsidies to conservation incentives. Instead of giving farmers free power to pump water, agricultural budgets must be redirected to pay farmers for the water they *do not* use. Farmers could be compensated for adopting water-saving practices or crop diversification. Pilot programs that experiment with rationing electricity and offering direct cash transfers for unconsumed power have shown early, highly effective promise in reducing pumping hours without harming farmer incomes (Fishman *et al.*, 2020).

Conclusion: Redefining the Revolution

India has undeniably won the global production race, but we must soberly acknowledge what kind of race it actually was. Driven by the historical trauma of famine, the nation engineered itself from a vulnerable subcontinent into an export powerhouse. This success is often framed as a triumph of policy, technology, and farmer resilience; a continuation of the Green Revolution's legacy.

But Producing "**more**" is no longer the benchmark of success. Producing "**smart within ecological limits**"is.The production boom has been sustained not just by better seeds or irrigation infrastructure, but by an increasingly unsustainable dependence on groundwater. Satellite-based estimates show that hundreds of cubic kilometres of groundwater have been lost in northern India over the past two decades, driven largely by irrigation-intensive cropping systems (Dangar& Mishra, 2024). In key rice-growing regions, extraction rates already exceed natural recharge by 35–57%, pushing aquifers into "critical" or "over-exploited" categories. Groundwater today supports more than 60% of India's irrigated agriculture, making this depletion not just an environmental issue, but a systemic risk to food security itself (Cao & Roy, 2025). Rice alone consumes nearly 40% of India's total irrigation water (Mallareddy *et al*., 2023).

By dominating the international rice trade, India has simultaneously become one of the world's largest net exporters of "virtual groundwater." When millions of tonnes of heavily irrigated rice are shipped overseas, billions of cubic meters of non-renewable subterranean water are effectively exported alongside them. So, as recent research underscores, the very cropping patterns that delivered food security are now undermining long-term water sustainability, necessitating a structural transition toward less water-intensive systems (Dangar & Mishra, 2024). It requires an absolute prioritization of resource efficiency over sheer volume,hydrological balance over short-term surplus and resilience over extraction-driven productivity.This is not a call to reduce ambition, but to redefine it.Being the world's breadbasket is a noble burden, but India must ensure it doesn't turn its own lands into a dustbowl to carry it.

There is an undeniable moral weight to India's role in the global food system. Feeding millions beyond its borders is not just an economic function; it is a geopolitical and humanitarian responsibility. But that responsibility cannot come at the cost of exhausting its own ecological foundations. Being the world's breadbasket is a noble burden, but India must ensure it does not turn its own lands into a dustbowl to carry it.

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Integrated Nutrient Management for Sustained Production of Sunflower in Rice-fallow Gangetic Alluvial Land

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Abstract

A field experiment comprising on of eleven treatments on integrated nutrient management viz, control, 100% recommended dose of fertilizer at 80 kg N + 60 kg P_2O_5 + 60 kg K_2O/ha (RDF), 75%RDF+ FYM at 10 tonne/ha, 75%RDF + Azotobacter; 75%. RDF + PSB; 75% RDF+FYM + Azotobacter; 75%RDF+FYM+PSB; 50%. RDF + FYM +Azotobacter, 50% RDF ++FYM+ PSB;50%. RDF + Azotobacterand 50% RDF + PSB were laid out in a Randomized Block Design in rice fallow land. The results revealed that 75%, RDF+FYM+PSB showed their beneficial effects on LAI, CGR and RGR.The same treatment also showed better manifestation of yield attributes like capitulum Size, number of seeds/capitulum and 1000-sed weight. 75%RDF + FYM + PSB gave the highest yield of 3.75 tonnes/ha. The same treatment also showed highest percent of oil content, oil yield and protein yield. This treatment also accelerated the uptake of N, P and K. The highest net return was also received from the same treatment.

Introduction

Sunflower (*Helianthus annuus* L.) isa versatile shout duration, drought tolerant, salt resistant, day-neutral, widely adaptable comp (SeshaSailaSree and Shridhar, 2005) offers promise for its cultivation in rice fallow Gangetic alluvial land. Sunflower is afast growing and high yielding crop and thus it is expected to required more nutrients. In sustained production of sunflower in Gangetic alluvial plains application of fertilizers elements may prove to be most important factor in topping the yield potential of sunflower. Among nutrients, N plays important role in growth and yield of sunflower (Khalics and Cheema, 2005).Phosphorus has an important role in the process of photosynthesis in plants(Arnon, 1962). Potassium plays vital role on intensity of photosynthesis in crop plant (Richards, 1958). These three major nutrients considerably influence the seed yield of sunflower. However, integrated use of inorganic and organics may improve the soil productivity (Mankotia,2007). Farm Yard Manureimproves the soil properties and finally crop yield (Bhatia and Shukla, 1982).Phosphate-solubilizing Bactria (PSB) increases coup productivity by solubilization of in soluble phosphates and stimulates plant growth (Sutaliyaiand Singh, 2001). Use of bioinoculant likeAzotobacter can also supplement chemical fertilizers by increasing availability of nutrients (Hubbel*et al.,* 1979). Sustainability of higher yields could be achieved through integrated nutrient management (Singh *etal.*, 1998) Hence the present investigation has been attempted.

Materials and Methods

The experiment integrated nutrient consisting of twelve integrated nutrient management treatments Viz. T1- Control, T2- 100% recommended dose of fertilizer at 80 kg N + 60 kg P_2O_5 + 60 kg K_2O/ha (RDF), T3- 75%RDF+ FYM at 10 tonne/ha, T4- 75%RDF + Azetobacter,T5- 75%. RDF + PSB, T6- 75% RDF+FYM + Azotobacter, T7- 75%RDF+FYM+PSB, T8- 50%. RDF + FYM , T9- 50%. RDF + FYM +Azotobacter,T10- 50% RDF +FYM+ PSB, T11- 50%. RDF + Azotobacterand T12- 50% RDF + PSB was conducted in Randomized ‘Block Design replicated thrice in rice fallow land during winter seasons of 2019-20 and 2020-21 at The Experimental station of Calcutta University, Bruipur, South - 24 Parganas, West Bengal. The soil was Inceptisol sandy loam in texture, poor in organic carbon, available N and medium in available P and K with pH

TABLE 1. Effect of Integrated Nutrient Management on certain plant growth parameters of Sunflower

Treatments	Plant height (cm)			Dry Matter (g/plant)			Leaf Area Index at maximum 60 DAS		
	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled
Absolute control	173.9	175.3	174.6	387.0	415.3	401.2	3.63	4.2	3.92
100% RDF	183.4	185.4	184.4	687.0	806.3	746.7	4.66	6.1	5.38
75%RDF+FYM	185.6	188.0	186.8	577.0	823.7	700.4	4	5.9	4.95
75% RDF +FYM+ Azotobactor	188.8	190.0	189.4	530.0	802.7	666.4	3.88	5.6	4.74
75% RDF+ Azotobactor	187.1	189.9	188.5	519.7	812.0	665.9	3.72	5	4.36
75% RDF +FYM+ PSB	194.7	193.9	194.3	869.3	868.7	869.0	4.98	6.4	5.69
75% RDF + PSB	187.6	190.0	188.8	648.0	848.3	748.2	4.16	5.6	4.88
50%RDF +FYM	185.4	187.8	186.6	643.0	815.0	729.0	3.81	5.6	4.71
50% RDF +FYM+ Azotobactor	185.4	187.8	186.6	677.0	746.7	711.9	4.3	5.3	4.8
50% RDF+ Azotobactor	182.9	185.3	184.1	676.0	737.8	706.9	4.63	5	4.82
50% RDF +FYM+ PSB	181.3	190.5	185.9	666.0	731.7	698.9	4.04	4.9	4.47
50% RDF + PSB	181.2	183.8	182.5	664.7	753.3	709.0	4.68	5	4.84
SEm +/-	4.1	4.8	4.9	13.3	21.6	12.5	0.08	0.05	0.04
CD (P=0.05)	8.6	1.7	9.8	28.0	45.4	26.2	0.23	0.13	0.11

TABLE 2. Effect of Integrated Nutrient Management on certain plant growth parameters of Sunflower

Treatments	Crop Growth Rate CGR (g/day) 45-60 DAS			Relative Growth rate RGR (g/g/plant) 35-45 DAS			Net Assimilation Rate NAR (10^{-3}/day/plant) 45-60 DAS		
	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled
Absolute control	5.39	2.98	4.19	0.23	0.30	0.27	5.55	6.19	5.87
100% RDF	7.64	6.38	7.01	0.22	0.28	0.25	5.35	6.03	5.69
75%RDF+FYM	6.85	5.01	5.93	0.23	0.28	0.26	5.33	6.10	5.72
75% RDF +FYM+ Azotobactor	6.74	4.47	5.61	0.23	0.29	0.26	5.51	6.09	5.80
75% RDF+ Azotobactor	6.76	4.35	5.56	0.23	0.29	0.26	5.80	6.21	6.01
75% RDF +FYM+ PSB	8.23	6.44	7.34	0.21	0.27	0.24	5.08	5.76	5.42
75% RDF + PSB	7.60	5.71	6.66	0.23	0.28	0.26	6.03	6.10	6.07
50%RDF +FYM	7.17	5.81	6.49	0.23	0.29	0.26	5.75	7.01	6.38
50% RDF +FYM+ Azotobactor	8.06	5.82	6.94	0.21	0.28	0.25	5.70	6.94	6.32
50% RDF+ Azotobactor	8.03	5.78	6.91	0.21	0.28	0.25	5.65	7.78	6.72
50% RDF +FYM+ PSB	7.71	5.75	6.73	0.21	0.29	0.25	5.90	7.44	6.67
50% RDF + PSB	8.05	5.63	6.84	0.21	0.28	0.25	5.55	7.19	6.37
SEm +/-	0.02	0.03	0.05	0.03	0.04	0.03	0.07	0.01	0.07
CD (P=0.05)	0.36	0.44	0.43	0.03	0.03	0.02	0.20	0.04	0.02

TABLE 3. Effect of Integrated Nutrient Management on yield attributes and yield of Sunflower

Treatments	Head diameters (cm)			Number of filled seed per head			Test weight 1000seed weight (g)		
	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled
Absolute control	12.98	14.70	13.84	568	744	656	34.0	34.7	34.4
100% RDF	17.80	20.07	18.94	1085	1282	1184	38.7	39.2	39.0
75%RDF+FYM	17.80	19.58	18.69	1072	1211	1142	38.7	38.4	38.6
75% RDF +FYM+ Azotobactor	17.74	19.85	18.80	1030	1326	1178	37.7	38.2	38.0
75% RDF+ Azotobactor	17.00	18.86	17.93	1038	1321	1180	38.8	·37.9	38.4
75% RDF +FYM+ PSB	19.82	21.38	20.60	1141	1385	1263	39.4	39.9	39.7
75% RDF + PSB	17.38	20.41	18.89	934	1174	1054	38.4	39.2	38.8
50%RDF +FYM	18.00	19.67	18.84	892	1163	1028	38.8	39.1	39.0
50% RDF +FYM+ Azotobactor	18.76	18.70	18.73	963	1145	1054	38.5	38.1	38.3
50% RDF+ Azotobactor	18.44	18.39	18.42	944	1113	1029	38.0	37.9	38.0
50% RDF +FYM+ PSB	17.81	18.31	18.06	863	1102	983	38.6	37.4	38.0
50% RDF + PSB	18.70	19.67	19.18	809	1021	915	38.7	39.1	38.9
SEm +/-	0.213	0.279	0.194	18	20	14	0.2	0.227	0.27
CD (P=0.05)	0.622	0.817	0.566	54	57	42	0.56	0.67	0.74

TABLE 4: Effect of Integrated Nutrient Management on yield of Sunflower

Treatments	Seed yield (t/ha)			Stover yield (t/ha)			Biological yield /(t/ha)			Harvest Index		
	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled
Absolute control	1.61	2.15	1.88	2.28	2.69	2.49	3.89	4.84	4.37	41.39	44.42	43.07
100% RDF	3.50	4.19	3.85	4.11	5.16	4.64	7.61	9.35	8.48	45.99	44.81	45.34
75%RDF+FYM	3.46	3.88	3.67	3.67	5.20	4.44	7.13	9.08	8.11	48.53	42.73	45.28
75% RDF +FYM+ Azotobactor	3.33	4.22	3.78	4.10	5.19	4.65	7.43	9.41	8.42	44.82	44.85	44.83
75% RDF+ Azotobactor	3.36	4.30	3.83	3.98	5.09	4.54	7.34	9.39	8.37	45.78	45.79	45.79
75% RDF +FYM+ PSB	3.75	4.61	4.18	4.21	5.36	4.79	7.96	9.97	8.97	47.11	46.24	46.63
75% RDF + PSB	2.99	3.84	3.42	3.78	5.13	4.46	6.77	8.97	7.87	44.17	42.81	43.39
50%RDF +FYM	2.80	3.67	3.24	3.81	5.12	4.47	6.61	8.79	7.70	42.36	41.75	42.01
50% RDF +FYM+ Azotobactor	3.01	3.64	3.33	3.29	4.75	4.02	6.30	8.39	7.35	47.78	43.38	45.27
50% RDF+ Azotobactor	2.92	3.52	3.22	3.28	4.52	3.90	6.20	8.04	7.12	47.10	43.78	45.22
50% RDF +FYM+ PSB	2.67	3.43	3.05	3.41	4.51	3.96	6.08	7.94	7.01	43.91	43.20	43.51
50% RDF + PSB	2.61	3.33	2.97	3.21	4.32	3.77	5.82	7.65	6.74	44.85	43.53	44.10
SEm +/-	0.05	0.04	0.06	0.04	0.04	0.05	0.04	0.05	0.04	0.34	0.46	0.52
CD (P=0.05)	0.15	0.23	0.22	0.27	0.44	0.18	0.14	0.17	0.15	1.27	1.78	1.48

TABLE 5. Effect of Integrated Nutrient Management on oil content, oil yield and protein content of Sunflower

Treatments	Oil concentration in seed (%)			Oil yield (kg/ha)			Protein content (%)		
	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled
Absolute control	39.80	40.00	39.90	640.78	860.00	750.12	11.30	12.40	11.85
100% RDF	41.20	42.30	41.75	1442.00	1772.37	1605.29	15.60	14.60	15.10
75%RDF+FYM	41.40	42.50	41.95	1432.44	1649.00	1539.57	14.60	14.80	14.70
75% RDF +FYM+ Azotobactor	41.60	42.60	42.10	1385.28	1797.72	1589.28	15.00	14.90	14.95
75% RDF+ Azotobactor	41.40	41.80	41.60	1391.04	1797.40	1593.28	14.60	14.50	14.55
75% RDF +FYM+ PSB	42.70	43.70	43.20	1601.25	2014.57	1805.76	15.20	15.60	15.40
75% RDF + PSB	41.20	40.60	40.90	1231.88	1559.04	1396.74	13.80	14.40	14.10
50%RDF +FYM	41.40	41.80	41.60	1159.20	1534.06	1345.76	13.80	14.00	13.90
50% RDF +FYM+ Azotobactor	41.00	41.80	41.40	1234.10	1521.52	1376.55	13.30	13.80	13.55
50% RDF+ Azotobactor	40.70	41.50	41.10	1188.44	1460.80	1323.42	12.10	13.90	13.00
50% RDF +FYM+ PSB	40.40	41.10	40.75	1078.68	1409.73	1242.88	13.90	13.90	13.90
50% RDF + PSB	40.30	41.10	40.70	1051.83	1368.63	1208.79	13.80	13.80	13.80
SEm +/-	0.7	0.8	0.7	118.8	90.6	88.5	0.5	0.5	0.3
CD (P=0.05)	1.6	1.6	1.4	249.5	190.3	161.6	1.0	0.9	0.8

TABLE 6. Effect of Integrated Nutrient Management on total nutrient uptake by Sunflower crop

Treatments	N uptake (kg/ha)			Phosphorus uptake (kg/ha)			Potassium uptake(kg/ha)		
	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled
Absolute control	36.52	40.10	38.31	11.61	14.59	13.10	19.01	26.52	22.75
100% RDF	91.34	100.50	95.92	30.01	33.77	31.89	56.27	75.32	65.80
75%RDF+FYM	81.29	104.70	93.00	25.85	36.85	31.35	53.29	73.61	63.45
75% RDF +FYM+ Azotobactor	66.14	97.90	82.02	21.07	36.27	28.67	51.17	71.85	61.51
75% RDF+ Azotobactor	59.93	93.30	76.62	20.27	33.23	26.75	45.69	71.67	58.68
75% RDF +FYM+ PSB	101.84	128.50	115.17	34.66	44.92	39.79	60.62	91.72	76.17
75% RDF + PSB	81.37	118.80	100.09	25.81	42.94	34.38	54.17	76.40	65.28
50%RDF +FYM	79.37	112.20	95.79	24.02	41.88	32.95	43.71	67.39	55.55
50% RDF +FYM+ Azotobactor	83.20	107.80	95.50	32.28	35.57	33.93	36.47	62.49	49.48
50% RDF+ Azotobactor	77.69	97.30	87.50	31.24	32.74	31.99	33.19	58.76	45.98
50% RDF +FYM+ PSB	83.27	97.20	90.24	28.46	30.59	29.53	33.07	58.17	45.62
50% RDF + PSB	75.85	109.30	92.58	27.28	33.04	30.16	29.67	54.88	42.27
SEm +/-	4.9	6.4	4.65	2.0	2.2	2.0	4.7	3.5	3.5
CD (P=0.05)	10.3	13.5	12.9	4.2	3.6	4.3	5.9	5.1	4.4

Table 7. Effect of Integrated Nutrient Management on total nutrient uptake by Sunflower crop

Treatment	Yield (t/ha)	Increaseinyield (t/ha)	Grossreturn (Rs/ ha)	Value of increased produce (Rs. /ha)	Cost of Treatments (Rs. /ha)	Net profit (Rs. /ha)	Benefit: Cost ratio
Absolute control	1.88	-	20680				
100% RDF	3.84	1.96	42240	21560	2790	18998	6.72
75%RDF+FYM	3.67	1.79	40390	19690	2843	16847	5.92
75% RDF +FYM+ Azotobactor	3.75	1.90	41580	20900	3143	17657	5.44
75% RDF+ Azotobactor	3.83	1.95	42130	21450	3190	18260	5.72
75% RDF +FYM+ PSB	4.18	2.30	45980	25300	2893	12407	7.74
75% RDF + PSB	3.41	1.53	37510	16830	2143	14687	6.85
50%RDF +FYM	3.27	1.36	35640	14960	2145	12815	5.97
50% RDF +FYM+ Azotobactor	3.32	1.44	36520	15840	2545	13295	5.22
50% RDF+ Azotobactor	3.22	1.34	35420	14740	1795	12945	7.12
50% RDF +FYM+ PSB	3.5	1.17	33550	12870	2195	10675	4.86
50% RDF + PSB	2.87	0.99	31570	10890	1445	9445	6.53

Prevailingmarketrateofproduce:Sunflower-Rs.11.00/kg,Urea-Rs.6/kg,10:26:26-Rs.10/kg,PSB-Rs.100/kgandAzotobacter-Rs. 200/kg

6.5 Sunflower cv. JK-Chitra was sown in second fortnight of November in both the years. The crop was given lifesaving irrigation one each at budding, flowering and grain filling stage. Standard package of practices was adopted. The coup was harvested by the second fortnight of March. Chemical analysis was done following methods described by Jockson, (1973). Economics was computed with market price of inputs and output

Results and Discussion

The results and indicated higher plant height and dry matterproduction per plant (Tablet 1) with 75%. RDF + FYM + PSB might be due to rapidmineralization from inorganicand FYM along with PSB which facilitatedbalance nutrition of sunflower (Jayabal*et al.*, 2000). The maximum LAI and CGR wererecorded with integrated nutrient supply of 75%. RDF + FYM + PSB due to increase in number and size of individual leaf and efficient physiological and metabolic process in plant (Morton and Watson, 1948).

In geminal, higher RGR at control treatmentreflected low potentiality of production of photosynthates over higher rate of fertilization and diminish of RGR with advancement of growth probably due to limitation in light to the lower leavesat advanced stage (Taraka*etal*, 1964). Higher NAR may presumably be accounted for increase in LAI. Increase in yield attributeswith integrated supply of 75%. RDF + FYM + PSB is attributed to adequate nutrients availability and thusenhanced photosynthetic Efficiency and ultimately yield attributes (Ready*et al.*, 2015). Increased mineralization of N and P in addition to nutrient from biofertilizer might have increased the size of head diameter, number of seeds/head and test weight of seeds. Integrated nutrient supply at 75%. RDF + FYM + PSB resulted in higher grain yield due to better growth, enhanced yieldattributes and finally yield. Increased in yield seems to be associated with simultaneous increase in LAI, Biomass and RGR. Despite reduction in RGR and NAR, yield was not impaired at all probably due to a good balance in photosynthesis and respiration. The same treatment also gave higher stover and biological yields due to increased manufacture of carbohydrates (Watson *etal.,* 1965*)* and protein biosynthesis (Fujiwara, 1965). Higher harvest index in 75%. RDF + FYM + PSB was mainly due to higher economic yield.

Application of 75%. RDF + FYM + PSB showed accelerating effect on oil content, oil yield and protein content. The impact of 75%. RDF + FYMwith PSB which added more P played a role in enhancing the glucoside content in seed which upon hydrolysis and esterification resulted in higher oil content in seed (Krishnamanthy and Mathan, 1996). The higher oil under75%. RDF + FYM + PSB was obviously because of higher seed yield and oil content. Seed protein content increased due to balanced supply of nutrients which accelerated protein synthesis in seed (Upper and Kulkarni, 1989). Increased the fertility up to 75%. Recommended NPK and integrated with FYMand supplementary inoculation of PSBresulted in higher uptake of N, P and K in general. This wasdue to integration of FYM and PSB with fertilizers upon decomposition might have improved nutrients availability in soil. Higher yield level in this integrated nutrient supply system than the control also resulted in more uptake of nutrients. Higher uptake of 75% RDF integrated with FYM and inoculation with PSB might be due to more nutrients from the Soil (Singh and Singh, 2006).

The net monetary returns and benefit-cost ratio were appreciably higher with 75%. RDF integrated with FYM and PSB. This can be attributed to the lower input cost due to reduced level of 75% RDF but at higher seedyield than that of 100% RDF resulting in higher benefit-cost ratio than that of 100% RDF.Thus, substitution of fertilizers at 75% in conjunction with FYM andPSB application seem to be most effective for improving productivity. and profitability in sunflower production.

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System of Mustard Intensification: A Pathway to Sustainable Intensification and Enhanced Oilseed Productivity in Rice-Fallow Agroecosystems

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Abstract

Indian mustard (*Brassica juncea* L.) is an important oilseed crop in India and plays a crucial role in meeting the country's edible oil demand. However, its productivity in many regions, particularly in the rice-fallow ecosystems of eastern India, remains low due to delayed sowing, poor crop establishment, moisture stress, inefficient resource use, and pest infestation. The System of Mustard Intensification (SMI), developed from the principles of the System of Rice Intensification (SRI), has emerged as a promising approach for improving mustard productivity through better crop and resource management. SMI promotes the use of nursery-raised seedlings, wider spacing, lower seed rate, integrated nutrient management, need-based irrigation, and regular intercultural operations. These practices encourage stronger root development, improved nutrient uptake, better canopy growth, and efficient utilization of available resources. The system also contributes to improved soil health and may help reduce pest incidence through enhanced crop vigour and canopy aeration. Despite its potential advantages in terms of productivity, profitability, and resource-use efficiency, the adoption of SMI remains limited due to factors such as high labour requirements, technical skill demands, inadequate mechanization, and limited farmer awareness. Strengthening extension services, promoting suitable farm implements, and developing location-specific recommendations can help overcome these constraints. Overall, SMI offers a sustainable and efficient strategy for enhancing mustard production, improving farm profitability, and contributing to India's efforts toward greater self-reliance in edible oil production.

Keywords: *Brassica juncea, System of Mustard Intensification, mustard productivity, resource-use efficiency, rice-fallow ecosystem, sustainable agriculture, edible oil security.*

Introduction

Indian mustard (*Brassica juncea* L.) and other cultivated *Brassica* species are among the most important oilseed crops grown across the world. In India, rapeseed-mustard occupies a prominent position among edible oilseed crops, ranking next to soybean in terms of importance (Chand *et al.*, 2021). The crop plays a significant role in meeting the country's edible oil demand and contributes considerably to agricultural income and rural livelihoods. Its popularity is largely due to its high oil content, adaptability to a wide range of agro-climatic conditions, and suitability for inclusion in diverse cropping systems.

West Bengal is one of the leading mustard-producing states in eastern India. The crop is generally cultivated during the rabi season after the harvest of Aman rice. However, the late maturity of many Aman rice varieties often delays land preparation, leaving a narrow window for mustard sowing. Consequently, farmers frequently establish the crop under less-than-ideal conditions (Sharma, 2016). In many areas, mustard cultivation depends largely on the residual moisture remaining in the soil after rice harvest, particularly where irrigation facilities are limited. Although this practice reduces the immediate need for irrigation, successful crop establishment becomes highly dependent on prevailing weather conditions. Insufficient rainfall during the post-harvest period can result in poor germination and moisture stress during the early stages of growth.

Mustard cultivation in rice-fallow ecosystems presents additional challenges. Following puddled rice cultivation, soils often remain compacted and poorly aerated, which can hinder root penetration and limit the uptake of water and nutrients (Kalita et al., 2020). Such conditions adversely affect crop establishment and plant growth, ultimately reducing productivity. Therefore, improving the management of mustard under rice-fallow situations remains an important area of research and development in eastern India.

Despite being one of the world's largest producers of oilseeds, India continues to experience a significant gap between domestic edible oil production and consumption. Rapid population growth, urbanization, changing food habits, and increasing purchasing power have contributed to a steady rise in edible oil demand (Mustafa & Iqbal, 2021). At present, domestic production meets only a portion of the national requirement, while a substantial share is fulfilled through imports. The country spends a large amount of foreign exchange annually on edible oil imports, creating economic pressure and increasing vulnerability to fluctuations in global markets and supply chains.

To address this challenge, increasing domestic oilseed production has become a national priority. Various government initiatives, including the National Mission on Edible Oils–Oilseeds (NMEO-OS), have been introduced to promote oilseed cultivation and improve self-sufficiency in edible oil production (Barik, 2023). Among the available options, enhancing mustard productivity is considered a practical and effective strategy, particularly in eastern India where considerable scope exists for improving crop yields.

The productivity of mustard in several regions of India, including West Bengal, remains lower than its potential (Dutta, 2016). Traditional cultivation methods often involve excessive seed rates, overcrowded plant populations, inefficient nutrient management, and inadequate water-use practices. Such conditions intensify competition among plants for essential resources such as light, water, nutrients, and space. As a result, plant growth is restricted, canopy development is compromised, and overall resource-use efficiency declines.

Insect pests also pose a major threat to mustard production. Among them, the mustard aphid (*Lipaphis erysimi* Kalt.) is regarded as one of the most damaging pests. Aphids feed on plant sap, weaken plant growth, reduce photosynthetic activity, and ultimately lower both seed yield and oil content (Sun et al., 2016). Their populations can increase rapidly under favourable environmental conditions. Dense crop stands and poor air circulation within the canopy often create an environment conducive to aphid infestation, making pest management a critical component of successful mustard cultivation.

In recent years, the System of Mustard Intensification (SMI) has gained attention as an innovative and resource-efficient approach for improving mustard production. Developed from the principles of the System of Rice Intensification (SRI), SMI focuses on creating favourable conditions for individual plant growth rather than relying heavily on external inputs. The system generally involves lower seed rates, wider plant spacing, improved organic matter management, timely intercultural operations, mechanical weed control, and irrigation based on crop requirements (Materu, 2025). These practices are intended to promote stronger root development, enhance nutrient uptake, improve photosynthetic performance, and increase overall productivity.

Although several studies have reported favourable effects of SMI on crop growth, yield, and profitability, available information remains limited and scattered across different locations and management conditions (Shah & Wu, 2019). Comprehensive studies evaluating the performance of SMI under the varied agro-climatic situations of West Bengal are still inadequate. Information on its long-term effects on soil health, resource-use efficiency, pest dynamics, economic returns, and farmer acceptance is also limited. Furthermore, the performance of different mustard varieties under SMI-based cultivation and their interaction with local environmental conditions require further investigation. Therefore, systematic research is needed to assess the potential of SMI as a sustainable strategy for enhancing mustard productivity and profitability in the rice-fallow ecosystems of West Bengal.

2. Principles of System of Mustard Intensification (SMI)

The System of Mustard Intensification (SMI) is founded on a set of agronomic and ecological principles designed to create favourable growing conditions for individual plants. Rather than increasing production through higher external inputs, the system focuses on improving the efficiency with which plants utilize available resources such as nutrients, water, sunlight, and growing space.

A fundamental principle of SMI is the use of a lower seed rate compared with conventional cultivation methods. By maintaining fewer plants per unit area, competition for essential resources is considerably reduced. Each plant receives adequate access to light, moisture, nutrients, and space, which promotes healthier growth and better overall performance. The reduction in plant competition also allows plants to express their genetic yield potential more effectively (Pandit *et al.*, 2022).

Wider spacing between plants is another key feature of the system. Unlike traditional methods that often involve dense planting, SMI recommends maintaining sufficient spacing between individual plants. This arrangement improves light penetration and air movement within the crop canopy, creating a more favourable microenvironment for plant growth. Better canopy development and enhanced photosynthetic activity ultimately contribute to improved crop productivity (Kumar *et al.*, 2024).

The development of a vigorous root system is also central to the success of SMI. Young seedlings transplanted under this system generally establish quickly and develop extensive root networks. Strong root growth enables plants to explore a larger volume of soil, thereby improving their ability to absorb water and nutrients. Enhanced root activity also helps plants withstand periods of environmental stress more effectively.

Maintaining soil health is another important component of SMI. The use of organic materials such as farmyard manure, compost, and other organic amendments improves soil structure and increases biological activity. These practices encourage the growth of beneficial microorganisms, enhance nutrient availability, and contribute to the long-term sustainability of the production system. Healthy soils not only support better crop growth but also improve the efficiency of applied inputs.

Weed management under SMI relies largely on mechanical and intercultural operations. Besides suppressing weed growth, these practices loosen the soil and improve aeration around the root zone. Improved soil aeration promotes root development and supports beneficial microbial activity, both of which are essential for healthy crop growth.

Water management is another critical aspect of the system. Irrigation is applied according to crop requirements rather than following a fixed schedule. Such need-based water management helps maintain adequate soil moisture while avoiding excessive water application. As a result, plants are protected from both moisture stress and waterlogging, leading to more efficient use of available water resources.

Taken together, these principles emphasize the integrated management of plants, soil, nutrients, and water. By creating favourable conditions for growth throughout the crop cycle, SMI seeks to improve productivity, resource-use efficiency, and sustainability in mustard cultivation.

CARE AND MANAGEMENT

(Source: Dhukia, M. (n.d.). *System of mustard intensification SMI* [PowerPoint slides]. SlideShare. https://www.slideshare.net/slideshow/system-of-mustard-intensification-smi/83507770)

Nursery Preparation

The foundation of a successful System of Mustard Intensification (SMI) crop lies in the production of healthy and robust seedlings. Unlike the conventional method of direct seeding, SMI involves raising seedlings in a nursery and subsequently transplanting them into

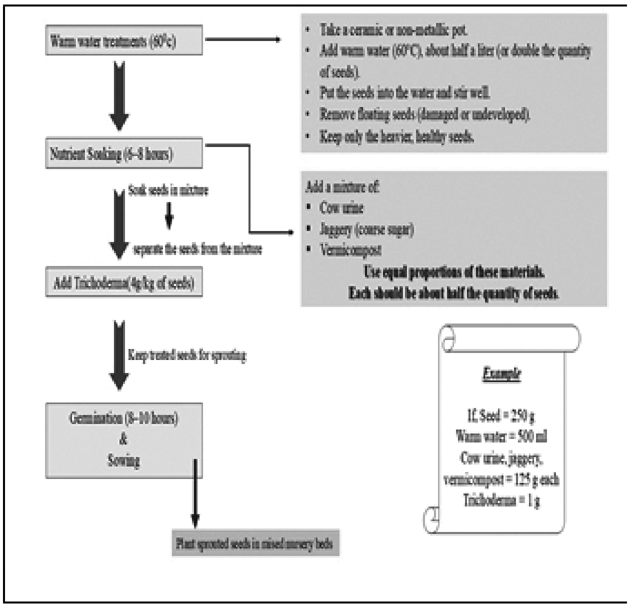

Fig 1. Flow diagram of the seed treatment and nursery establishment protocol used in the System of Mustard Intensification (SMI), including warm water treatment (60°C), nutrient soaking, Trichoderma seed treatment, sprouting, and sowing of pre-germinated seeds in raised nursery beds.

the main field. This practice facilitates better crop establishment and allows each plant to grow under less competitive conditions.

For nursery raising, a raised bed of about 10–15 cm height and one metre width is generally prepared to ensure proper drainage and aeration. Pre-germinated seeds are sown shallowly, usually at a depth of 1–1.5 cm, while maintaining sufficient spacing between seeds. To promote uniform germination and conserve moisture, the beds are covered with a thin layer of vermicompost followed by paddy straw mulch. Light irrigation is provided through sprinkling,

preferably during the morning and evening hours, to maintain adequate moisture in the nursery. Depending on the duration of the variety, approximately 20–60 m² of nursery area is sufficient for planting one hectare of the main field.

Seedlings raised under these conditions tend to establish quickly after transplanting and develop stronger root systems. Vigorous seedlings are capable of utilizing nutrients and moisture more efficiently, which ultimately contributes to better plant growth and yield performance.

Main Field Preparation

Proper land preparation is essential for obtaining the full benefit of SMI practices. The field is usually ploughed two or three times to achieve a fine tilth and to create a favourable environment for root growth. If the soil is dry, a pre-sowing irrigation may be applied before final land preparation.

After levelling, the field is marked according to the desired planting geometry. Small pits are then prepared at the designated planting points. These pits are filled with a mixture of compost, soil, diammonium phosphate (DAP), muriate of potash (MOP), and *Trichoderma*. Compost improves soil physical condition and nutrient availability, while *Trichoderma* helps suppress soil-borne pathogens and promotes healthy root development. The combined use of organic and inorganic inputs supports better soil fertility and creates a favourable environment for crop growth.

Transplanting under SMI

Transplanting is one of the key features that distinguishes SMI from conventional mustard cultivation. Before seedlings are removed, the nursery beds are irrigated thoroughly so that uprooting can be carried out with minimum damage to the roots. Generally, seedlings are transplanted at the 3–4 leaf stage when they are young and capable of recovering rapidly from transplanting shock.

Under SMI, plants are arranged in a square pattern, maintaining equal spacing in both directions. The spacing adopted depends on the duration and growth habit of the variety. Short-duration cultivars may be planted at 30 × 30 cm spacing, whereas long-duration cultivars may require spacing up to 75 × 75 cm. Wider spacing minimizes competition among plants and enables each plant to receive adequate sunlight, nutrients, moisture, and growing space. As a result, plants develop more branches, larger canopies, and stronger root systems, which contribute positively to yield.

Management up to 30 Days after Transplanting

The first month after transplanting is critical for crop establishment. During this period, emphasis is placed on maintaining adequate soil moisture and ensuring sufficient nutrient availability for early growth. The first irrigation is usually given about 15 days after transplanting. This is followed by the application of urea at approximately 27 kg per acre near the root zone. Nitrogen supplied at this stage encourages leaf development, chlorophyll formation, and rapid vegetative growth. Weeding is generally undertaken around 20 days after transplanting to eliminate competition from weeds. During this operation, vermicompost and phosphate-solubilizing bacteria (PSB) may be incorporated into the soil.

Vermicompost improves soil fertility and microbial activity, while PSB helps make phosphorus more readily available to plants. Around 30 days after transplanting, a second irrigation is provided, followed by another weeding operation and the application of Biozyme or similar biological formulations to support microbial activity and nutrient cycling within the soil.

Management from 35 to 50 Days after Transplanting

Between 35 and 50 days after transplanting, mustard plants exhibit rapid vegetative growth accompanied by increased branching and canopy expansion. To sustain this growth, a second dose of urea is generally applied around 35 days after transplanting and followed by irrigation. Split application of nitrogen helps maintain a continuous nutrient supply while reducing losses and improving nutrient-use efficiency.

At approximately 40 days after transplanting, muriate of potash is applied. This operation is usually combined with intercultural practices such as soil loosening and earthing-up around the base of the plants. Besides controlling weeds, these operations improve soil aeration and encourage root proliferation. Potassium plays an important role during this period by supporting various physiological functions, including enzyme activation, carbohydrate transport, and stress tolerance.

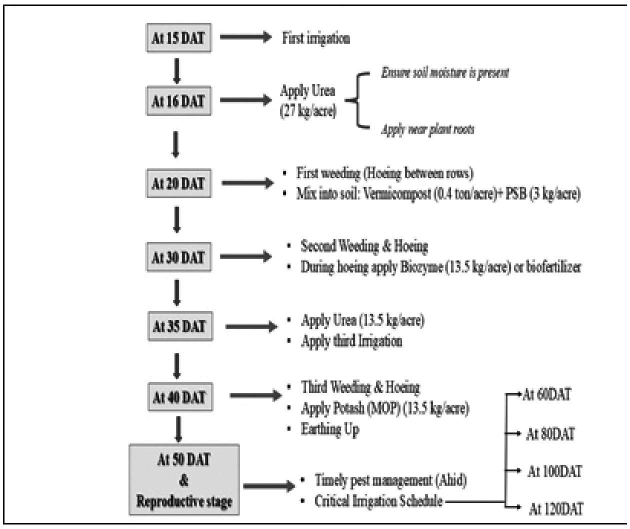

Fig 2: Schematic representation of irrigation, nutrient, and intercultural operations under the System of Mustard Intensification (SMI) from 15 DAT to the reproductive stage.

Management after 50 Days of Transplanting

After 50 days, the crop gradually enters the reproductive phase, during which flowering, siliqua development, and seed filling take place. Proper management during this period is crucial because these stages have a direct influence on final yield. Adequate soil moisture must be maintained throughout flowering and seed development. Depending on weather conditions and soil moisture availability, irrigations are commonly scheduled around 60, 80, 100, and 120 days after transplanting. Moisture deficiency during these stages may adversely affect pod formation, seed setting, and seed weight.

The crop also becomes vulnerable to insect pests, particularly mustard aphid (*Lipaphis erysimi*). Regular monitoring of the field is therefore necessary so that timely control measures can be adopted whenever required. The wider spacing followed under SMI improves air circulation within the crop canopy, which may help reduce the severity of pest and disease incidence compared with densely populated crops.

Overall, the management practices followed in SMI are aimed at creating favourable conditions for plant growth throughout the crop cycle. Timely irrigation, balanced nutrient application, use of organic amendments, biological inputs, and regular intercultural operations work together to enhance crop performance. By improving resource-use efficiency while maintaining soil health, SMI offers a sustainable and productive approach to mustard cultivation under a range of agro-climatic situations.

Problems in the Adoption of System of Mustard Intensification (SMI)

Studies conducted in different regions have indicated that SMI can improve growth, yield attributes, and resource-use efficiency when compared with conventional cultivation methods. Despite these potential advantages, the adoption of SMI by farmers remains relatively limited. Several technical, operational, economic, and institutional factors influence farmers' willingness and ability to adopt the system on a larger scale. Understanding these constraints is essential for developing strategies that can facilitate wider acceptance of the technology.

Technical and Physiological Constraints

One of the major challenges associated with SMI is the transplantation of young seedlings. Unlike direct-seeded mustard, SMI involves raising seedlings in a nursery and transplanting them into the main field. Mustard possesses a delicate taproot system, and improper handling during transplanting may cause root injury or transplanting shock. Damage to the primary root can affect subsequent root growth, nutrient uptake, and plant establishment, ultimately influencing crop performance.

Another limitation relates to varietal suitability. Most commercially cultivated mustard varieties have been developed and evaluated under conventional planting systems characterized by relatively high plant populations. Their performance under wider spacing conditions may not always be optimal. Varieties suitable for SMI should ideally possess greater branching ability, vigorous growth habits, and efficient utilization of available space. However, limited breeding efforts have been directed specifically toward the development of cultivars adapted to SMI conditions.

The wider spacing recommended under SMI also modifies the field microenvironment. Increased exposure of the soil surface to sunlight may accelerate moisture loss through evaporation, particularly during dry weather conditions. Consequently, maintaining optimum soil moisture becomes more important under SMI than under densely planted systems. In areas where irrigation facilities are inadequate or rainfall is uncertain, this requirement may pose a challenge for farmers (Pandit *et al.*, 2022).

Operational and Labour-Related Constraints

Labour requirement is often considered one of the most important barriers to the adoption of SMI. Activities such as nursery preparation, seedling care, transplanting, and intercultural operations demand greater labour input than conventional broadcasting or line sowing methods. The transplanting of young seedlings, in particular, requires careful handling and considerable time.

The timing of mustard transplantation often coincides with the harvesting and post-harvest operations of major kharif crops, especially rice. During this period, labour availability may become limited, leading to delays in field operations. Such delays can affect crop establishment and reduce the potential benefits associated with SMI.

In addition, successful implementation of SMI requires greater management precision. Farmers must pay attention to nursery management, seedling age, spacing, irrigation scheduling, and nutrient application. For many farmers who have long practiced conventional methods, adapting to these new management requirements may initially be difficult without adequate guidance and training.

Socio-Economic and Institutional Constraints

Farmer perception and risk considerations also influence the adoption of SMI. Fields planted under wider spacing often appear sparsely populated during the early stages of growth. Many farmers associate higher plant populations with higher yields and may therefore perceive widely spaced crops as risky. This psychological barrier can discourage experimentation and adoption, particularly among small and marginal farmers who are highly dependent on stable production.

Although SMI reduces seed requirements, it may involve additional expenditure on organic manures, biofertilizers, nursery management, and labour. For resource-constrained farmers, these initial investments may limit adoption, especially when access to credit and financial support is inadequate.

Another important limitation is the lack of suitable mechanization options. Most available agricultural implements are designed for conventional cultivation systems. Affordable and efficient tools for marking, transplanting, weeding, and other operations under SMI are not widely available. As a result, many activities continue to depend heavily on manual labour, increasing production costs and reducing operational efficiency.

Institutional support remains another area of concern. In many regions, farmers have limited exposure to SMI due to insufficient extension activities, inadequate demonstrations, and weak linkages between research organizations and farming communities. Without proper technical support and field-level guidance, adoption rates are likely to remain low (Barik, 2023).

Comparison between Conventional Mustard Cultivation and SMI

Feature	**Conventional Mustard Cultivation**	**Requirements/Challenges under SMI**
Seed Rate	Higher seed rate (5–8 kg ha{ ^{1})	Lower seed requirement (H”1 kg ha{ ^{1}) but demands precise seedling management and plant establishment
Crop Establishment	Direct sowing in the main field	Nursery raising and transplantation of young seedlings are required
Plant Population	Dense and often irregular plant stand	Wider and uniformly maintained spacing between plants
Water Management	Relatively less attention to irrigation scheduling; often flood irrigation where water is available	Need-based and timely irrigation management to maintain optimum soil moisture
Weed Management	Weed control is often difficult due to dense crop stand	Intercultural operations are easier because of wider spacing, but appropriate tools and labour are required
Labour Requirement	Comparatively lower labour demand	Higher labour requirement, particularly for nursery management and transplanting
Nutrient Management	Primarily dependent on chemical fertilizers	Greater emphasis on integrated nutrient management involving organic and biological inputs
Skill Requirement	Familiar and widely practiced by farmers	Requires technical knowledge, training, and careful management
Risk Perception	Considered less risky due to traditional acceptance	Farmers may perceive risk because of sparse initial plant population and unfamiliar practices

Strategies for Enhancing Adoption

The successful expansion of SMI depends on addressing the constraints faced by farmers. Establishing community-based nurseries can reduce the burden of seedling production and ensure the availability of healthy planting material. Such collective approaches may also lower production costs and improve access to quality seedlings.

The development and dissemination of low-cost tools for marking, transplanting, and weeding can help reduce labour requirements and improve operational efficiency. Increased mechanization would make the technology more attractive to farmers, particularly in areas experiencing labour shortages.

Strengthening extension services is equally important. Demonstrations conducted under local conditions can help farmers observe the benefits of SMI directly and build confidence in the technology. Extension programs should provide location-specific recommendations that take into account local soil conditions, climate, irrigation availability, and existing cropping systems.

Regular training and capacity-building programs can further improve farmers' knowledge and technical skills. Hands-on training related to nursery management, transplanting techniques, nutrient management, and pest control can significantly enhance the effectiveness of SMI implementation.

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