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RESEARCH AND REVIEWS IN AGRICULTURE SCIENCE VOLUME II

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Research and Reviews in Agriculture Science

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PREFACE

Agriculture is the cornerstone of human civilization, providing sustenance, raw materials, and economic stability for societies around the world. As our global population continues to grow and environmental challenges become increasingly complex, the importance of agriculture in ensuring food security, environmental sustainability, and economic prosperity cannot be overstated. To meet these challenges, agricultural science has evolved rapidly, embracing interdisciplinary approaches, technology-driven solutions, and sustainable practices.

In this book, we have gathered a selection of research papers and reviews that delve into various facets of agriculture, from crop science and livestock management to soil health, agribusiness, and the integration of cutting-edge technologies. Each chapter represents a unique contribution to the ongoing dialogue in agricultural science, shedding light on emerging trends, innovative methodologies, and critical insights that have the potential to shape the future of agriculture.

The content within these pages spans a wide spectrum of topics, providing a holistic view of the challenges and opportunities that lie ahead in agriculture. Whether you are a seasoned researcher, a student embarking on a journey in agricultural science, or a stakeholder in the agriculture industry, we believe that this book will offer valuable perspectives and inspire further inquiry into the fascinating and ever-evolving field of agriculture.

We extend our gratitude to the authors who have generously shared their expertise and findings, as well as the reviewers who have dedicated their time and expertise to ensure the quality and rigor of the content presented here. This collaborative effort is a testament to the spirit of inquiry and the shared commitment to advancing agricultural knowledge.

As we navigate the complexities of feeding a growing global population, protecting our natural resources, and fostering sustainable agricultural practices, it is our hope that "Research and Reviews in Agriculture Science" will serve as a valuable resource and source of inspiration for all those engaged in the pursuit of a more resilient and sustainable future for agriculture.

Editors

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MICROGRAFTING IN FRUIT CROPS

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Abstract:

Micrografting is an *in vitro* grafting technique which involves the placement of a meristem or shoot onto a decapitated rootstock that has been grown aseptically from seed or micropropagated cultures. In fruit crops, initially micrografting technique was developed in citrus to obtain pathogen free plants. Later it was developed in other woody species such as apple, pear, pistachio, plum, peach, almond, grape vine, mulberry, olive, hazelnut, chestnut, walnut, almond and mangosteen. This technique was mainly developed to avoid graft-transmissible pathogens. Compared to the traditional grafting, micrografting has potential advantages such as elimination of viruses, more rapid and year-round plant production, requirement of less space and high quality true-to-type plants. Micrografting has many important applications such as safe germplasm exchange, indexing viral diseases, regeneration of somatic hybrids, regeneration of plants from irradiated shoots and regeneration of haploid plants. Success of grafting depends upon different factors *viz*., method of grafting, type and age of rootstock, size of scion and growth regulators used.

Introduction:

Plants are mainly propagated through two methods; vegetative and sexual method. Sexual method has several disadvantages like high heterozygosity, long juvenility, seed transmissible diseases, excludes the benefits of rootstock and produces yield of inferior quality. Hence, we are mainly practicing vegetative means of propagation like grafting, budding, cutting and layering in horticultural crops. Grafting is a technique of vegetative propagation in which scion and rootstock are joined together so that they will grow as one plant. Grafted plants have short juvenile phase, it means they will produce flowers and fruits within 2-3 years of planting. Plants attain smaller stature and hence harvesting and spraying of chemicals become easy. Novel plants mean many varieties in a single plant can be created through this method Jitendra Singh. But the grafting method has a main disadvantage, such as the transmission of viral diseases. Therefore, the production of healthy plants is needed, and micrografting serves that purpose.

Micrografting

Micrografting is an *in vitro* grafting technique which involves the placement of a meristem onto a decapitated rootstock that has been grown aseptically from seed or micropropagated cultures (Hartmann *et al*., 2002).

History

The era of micrografting in fruit crops was started after the successful micrografting in citrus by Murashige and co-workers in 1972. Further this technique was improved in woody species by Navarro in 1975. After citrus, this technology has been standardized for apple, pear, pistachio, peach, plum, almond, grapevine, mulberry, olive, hazelnut, chestnut, walnut, almond and mangosteen. Purpose of micrografting is to avoid graft transmissible pathogens. Some of the successful micrografts are shown in Figure 1.

S/N	Fruit crop	Scion cultivar	Rootstock	Successful micrografts (%)	Source
1	Pistachio	*Pistacia vera* cv. Siirt	Seedling raised rootstocks	79.25	Onay et al. (2004)
2	Pistachio	*Pistacia vera* cv. Mateur	Seedling raised rootstocks	94-100	Abousalim and Mantell (1992)
3	Mulberry	(*Morus alba*) cv. 707	Seedling raised rootstocks	>90	Fengtong et al. (1996)
4	Olive	*Olea europea* cv. Zard	*In vitro* raised seedlings of olive	45-83	Farah et al. (2011)
5	Grape	*Vitis venifera* cvs. Sahebi, Soltanin, Fakhri	41 B	50.1 -60.6	Aazami and Bagher (2010)
6	Grape	*Vitis venifera* cv. Early Cardinal	41 B, Salt Creek	71.4 - 80.0	Tangolar et al. (2003)
7	Apple	*Malus domestica* cv. Lal Ambri	M-9 rootstock	42.25	Khalid Mushtaq (2009)
8	Hazelnut	E-295-S (hazelnut)	G-029-N	72.00	Nas and Read (2003)
9	Chestnut	907 (chestnut)	711	80.00	Nas and Read (2003)
10	Walnut	*Juglans regia* cvs. Jinlong No 1, Xiangling	Seedling raised rootstock	56.70 - 73.30	Wang et al. (2010)
11	Almond	*Amygdalus Communis* cvs. Ferragnes, Ferraduel	*In vitro* germinated wild almond seedlings	90-100	Yildirim et al. (2010)
12	Almond	*Amygdalus Communis* cv. Nonpareil	*In vitro* germinated wild almond seedlings	90.00	Isıkalan et al. (2011)
13	Almond	*Prunus dulcis* cvs. Texas, Ferrastar, Nonpareil	*In vitro* germinated almond seedlings	83.33 - 100	Yıldırım et al. (2013)
14	Citrus	I: Kinnow mandarin II Succari sweet orange	*In vitro* germinated seedlings of rough lemon	I 36 II 33.3	Naz et al. (2007)
15	Pear	Pyrus communis cv. Le-Cont	*In vitro* shoots of *Pyrus betulaefolia*	83.00	Hassanen (2013)

Fig. 1: Successful micrografts in fruit crops (Hussain *et al.,* 2014)

Advantages over conventional grafting

This method provides several advantages such as elimination of viruses, it is much more rapid, requires much less space, particularly disease-free planting materials, produces genetically uniform plantlets, rejuvenation of mature tissues, year round plant production, enhance compatibility studies and extension of ecological limits of a particular plant species (Isikalan *et al*., 2011). The differences between conventional grafting and micrografting is given in Table 1.

Table 1: Difference between conventional grafting and micrografting

Conventional grafting	Micrografting
➢ Bigger size scion of 15-20 cm long	➢ Smaller size scion of 0.1-0.3 mm apical meristem with 2-3 leaf primordia
➢ It is performed under open condition	➢ It is performed under controlled condition
➢ Slower rate of production	➢ Faster rate of production

Methods of *in vitro* grafting

Mainly there are three methods of micrografting are being followed in fruit crops, those are;

1. Vertical slit method

The rootstock will be decapitated to remove all the leaves and a vertical slit will be made on the stump. Scion base cut into 'V' shape and it will be fitted on to slit (Figure 2).

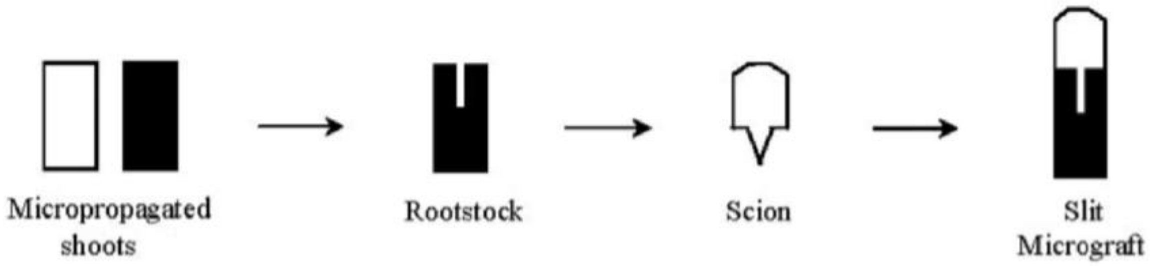

Fig. 2: Vertical slit method

2. Wedge method

The rootstock will be decapitated to remove all the leaves and wedge-shaped cut will be given on to stump and the scion base cut into 'V' shape and it will be fitted on to slit (Figure 3).

Fig. 3: Wedge method

3. Horizontal method:

The rootstock will be decapitated to remove all the leaves and horizontal cut will be given on both scion and rootstock and gently fixed (Figure 4).

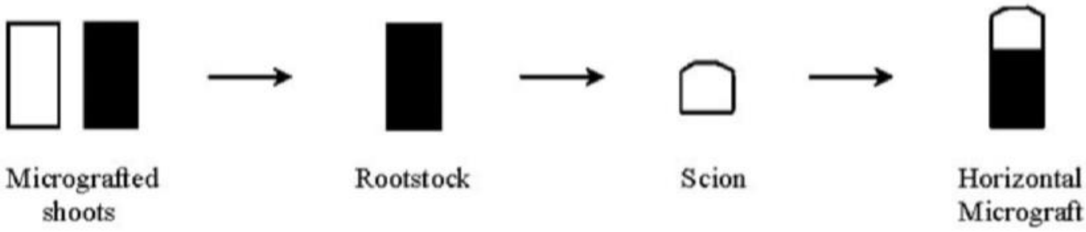

Fig. 4: Horizontal method

Steps in micrografting

The steps in micrografting are preparation of rootstock, preparation of scion, grafting, culture of *in vitro* grafted plants and transplanting to polythene bags.

1. Rootstock preparation

Preparation of rootstock involves, extraction of seeds from fruits then Seeds are peeled eliminating the outer and inner seed coats, surface sterilized by using 0.6 % of sodium hypochlorite solution and washed with distilled water, and cultured in tubes containing 25 ml of the plant cell culture salt solution of Murashige and Skoog with 1% bacto Agar. Cultures are incubated at 27°C in darkness for two weeks. Seedlings are stored at 4°C for at least two weeks without any detrimental effect on grafting success. This allows an easy selection of uniform seedlings. Under aseptic conditions the seedling is removed from the test tube and it is cut back, leaving about 1.5 cm of the epicotyl. The root is shortened to a length of 4-6 cm and the cotyledons and their axillary buds eliminated and this process is called decapitation (Navarro *et al*., 1975).

2. Scion preparation

Shoot tips can be excised from different sources like growing vegetative flushes or dormant buds from field or greenhouse plants and from shoots produced by budwoods or nodal buds cultured *in vitro*. Growing vegetative flushes from greenhouse plants or budwood cultured *in vitro* are the recommended sources since the incidence of successful grafts and pathogen elimination was higher in comparison to other sources. These shoot tips are cultured in tubes containing MS medium with 1 % bacto agar. The new flushes produced after 14-16 days are used for excision of micro scion (Navarro *et al*., 1975).

3. Grafting

Grafting can be done by making 1mm vertical incision or 1-2 mm horizontal incision on decapitated rootstock. Micro scion is placed inside the incision with its cut surface in contact with the cortex (Navarro *et al*., 1975).

4. Culture of *in vitro* grafted plants

Micrografted plants are cultured in a liquid nutrient medium composed of the plant cell culture salt solution of Murashige and Skoog, modified White's vitamins and 75 g L^{-1} sucrose. A folded paper platform, perforated in its centre for insertion of the root portion of the rootstock, is placed in the nutrient solution. The cultures are kept at constant 25°C and exposed 16 h daily to 40-50 µE m^{-2} s^{-1} illumination. Growing small leaves from the shoot tip coming out from the incision can be observed about 3-4 weeks after grafting and 4-6 weeks after grafting the successful grafts already have two to four expanded leaves and they can be transplanted to polythene bags (Navarro *et al*., 1975).

5. Transplanting

Scions of successful grafts should have at least two expanded leaves before being transplanted to soil. This stage is usually reached four to six weeks after grafting. Micrografted plants are transferred to pots containing steam-sterilized artificial soil mix. To avoid moisture loss, plants are enclosed in polythene bags and then placed in controlled greenhouse where temperature maintained at 18-25°C and after two weeks the plants are shifted to regular greenhouse conditions (Navarro *et al*., 1975).

Factors affecting success of micrografting

The success rate in micrografting can be affected by different factors such as the age of materials, grafting technique, sterilization conditions, the concentration and the application period of chemical used and the skill of the labour (Tangolor, 2014).

The study conducted by Kanwar and co-workers in 2019 to know the effect of age and type of rootstocks on success of micrografting when sweet orange cv. Blood red was grafted on different rootstocks like rough lemon, carrizo, sour orange and karna khatta and found that the maximum success of 66 % in rough lemon at 13 days old seedling followed by 62 % in carrizo at 15 days old seedling, 54 % in sour orange at 14 days old seedling and 52 % in karna khatta at 14 days old seedlings. This study indicates that, the success of *in vitro* grafting depends on type of rootstock used because of compatibility difference between rootstock and scion. The best results were obtained when two-week-old seedlings were used as rootstock and the seedlings less than 12 days and more than 18 days were found inferior. The sprouting in successful grafts was faster in rough lemon 16.4 days followed by carrizo citrange 17.8 days, 20 days karna khatta and 20.4 days in sour orange. This may due to compatibility difference between species to species. The maximum length of shoot was observed 1.88 cm in carrizo and rough lemon followed by sour orange 1.34 cm and karna khatta 0.98 cm. This difference due to growth habit of rootstock (Table 2 and Table 2.1).

A study was conducted by Kanwar and co-workers in 2019 to know the percent survival rate of grafted plants after shifting to polyhouses and found that after 15 days of shifting, the maximum of 95 % of survival rate was observed when blood red was grafted on rough lemon followed by 92 % on carrizo, 88 % on sour orange and 82 % on karna khatta. The higher survival rate of grafts on rough lemon and carrizo is due to comparative grafts compatability between rootstock and scion (Table 3).

Table 2: Effect of age and type of rootstocks on success of micrografting in sweet orange cv. Blood Red.

Age of seedling	**Rough lemon**			**Carrizo**		
	Success (%)	**Days taken to bud sprout**	**Length of shoot (cm)**	**Success (%)**	**Days taken to bud sprout**	**Length of shoot (cm)**
11						
12				42	**17.8**	1.74
13	36	**16.4**	1.32	**66**	18.4	**1.88**
14	44	16.8	1.7	62	18.4	1.62
15	**62**	17.6	**1.88**	52	19.4	1.5
16	54	19	1.46	48	20.4	1.22
17	46	19.6	1.06	46	21	1.02
18	40	20.6	0.76	44	21.4	0.8
19	36	21.6	0.84	40	22.4	0.78
20	34	22	0.74	28	22.6	0.72
Sem+	1.44	0.21	0.07	1.64	0.21	0.04
CD(P=0.05)	4.13	0.59	0.2	4.7	0.61	0.12

Table 2.1: Effect of age and type of rootstocks on success of micrografting in sweet orange cv. Blood Red.

Age of seedlings	Sour orange			Karna khatta		
	Success (%)	Days taken to bud sprout	Length of shoot (cm)	Success (%)	Days taken to bud sprout	Length of shoot (cm)
11						
12						
13						
14	**54**	**20.4**	**1.34**	**52**	**20**	**0.98**
15	50	20.6	1.14	48	20.4	0.86
16	48	21.4	0.92	44	20.6	0.72
17	44	21.6	0.84	42	22	0.66
18	42	22.2	0.66			
19						
20						
Sem+	1.15	0.19	0.02	0.97	0.11	0.02
CD(P=0.05)	3.29	0.55	0.06	2.78	0.31	0.05

Table 3: Percent survival of grafted plant on different rootstocks in polyhouse

No. of plantlets survival after grafting (in days)	Name of citrus species			
	Rough lemon (%)	Carrizo (%)	Sour orange (%)	Karna khatta (%)
15	**95**	**92**	88	82
30	92	90	82	74
60	90	87	75	70

In a study conducted by Bhatt and co-workers in 2013 to know the effect of grafting methods on contamination, vitrification, necrosis and graft success in apple shows that main effect of grafting methods on contamination and vitrification were found non-significant. Main effect of grafting methods on explant necrosis was significant. Highest necrosis of 40.36 % was observed under horizontal method which was decreased to 29.33 % when used vertical slit method. The highest grafting success of 23.83 % under vertical slit method of grafting and the lowest grafting success 13.10 % under horizontal method (Figure 2).

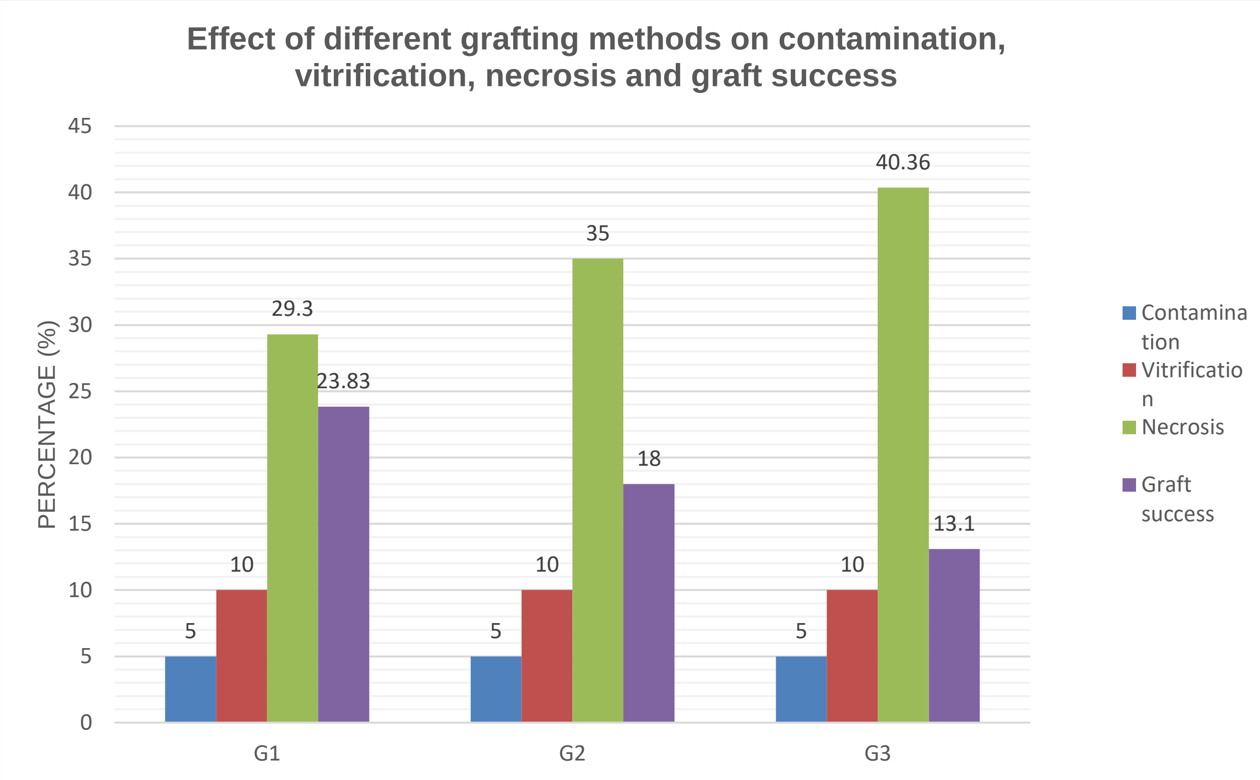

Fig. 2: Effect of different grafting methods on contamination, vitrification, necrosis and graft success

The study conducted by Onay and coworkers in 2004 to know the effect of age of scion on micrografts success in pistachio and found that the micrograft success increased with size of scion upto 4-6 mm and there after decreases with size (Table 4).

Table 4: Effect of scion size on success of pistachio micrografts

Scion size (mm)	Successful micrografts (%)
<0.50	0.00
0.50-1.0	27.20
2.0-4.0	56.75
4.0-6.0	**79.25**
>10.0	17.25

Applications of micrografting

1. Virus and viroid free plants

Meristems are relatively virus-free and meristematic tissues in the shoot tips and axillary buds normally remain virus-free because the growth of the meristem is quicker than the systematic spread of the virus within the plant. Using micro shoot tips as scions, micrografting produces plants that are virus-free and reproductively mature.

2. Production of plants resistant to pests and diseases

Micrografting can be used as means of elimination of pathogens in fruit crops. It has been successfully used in a wide range of horticultural plants as an effective method for the acquisition of plants resistant to soil borne pathogens. Grape phylloxera is considered as the most destructive pest of cultivated grapes worldwide, which feeds on the sap of grape roots, causing damage and often death of vines (Makee *et al*., 2004). An efficient and robust micrografting system was developed for production of phylloxera resistant plants in grapes by Kim *et al*. (2005) using pest resistant cultivars as rootstocks (Millardet et de Grasset 101-14, couderc 3309).

3. Assessment of graft incompatibility

The inability of two different plants when grafted together to produce a successful union and also to develop satisfactorily into one composited plant is termed as graft incompatibility. Prediction of incompatible graft combinations is very important area of study for preventing economic loss due to graft incompatibility. Signs of graft incompatibility are often detected after several years in the field but can be identified early using micrografting and *in vitro* callus fusion technique (Jonard *et al*., 1990; Errea *et al*., 2001).

4. Improvement of plant regeneration

Micrografting provides an alternative production technique for mass multiplication of plants which are difficult-to-root or propagation of difficult-to-root novel plants created in tissue cultures (Barros *et al*., 2005). This is done by micrografting micro shoots of difficult-to-root plants/cultivars on seedling rootstocks grown *in vitro*.

5. Indexing viral diseases

Grafting is used to determine the presence of latent viral diseases in plants. A plant (the indicator plant) that is known to be susceptible to the disease of interest may be grafted onto the suspect plant. If the plant is in question is infected, typical symptoms induced by the specific virus are expressed on the indicators after the virus has been moved into the indicator plants.

6. Safe germplasm exchange

Small micrografted trees are a convenient way to exchange germplasm between countries. The exchange of fruit tree propagation material between countries is a major cause of spread of new pests and pathogens, particularly graft-transmissible viruses and viroids. Tanne *et al*. (1993) used micrografting system which increased the speed of viral detection.

Regeneration practices in fruit crops

1. Regeneration of somatic hybrids

In protoplast fusion experiments, abnormal embryos are very often produced. These include multiple fascinated cotyledons, germinating embryos that only produce shoots or roots, or without a good vascular connection among shoot and root, and abnormal shoot proliferation, among other alterations. These embryos do not produce viable plants that can be established in the greenhouse, thus reducing the efficiency of recovery of somatic hybrids and loosing potentially valuable genotypes. These types of hybrids can be regenerated through micrografting (Juarez *et al*., 2015).

2. Regeneration of plants from irradiated shoots

Shoot tips are irradiated with gamma rays and then these shoots are regenerated through micrografting (Juarez *et al*., 2015).

3. Regeneration of haploid plants

Haploid plants usually have low establishment rate in greenhouses are regenerated through micrografting onto the rootstock (Juarez *et al*., 2015).

4. **Production of stable tetraploid plants**

Tetraploid plants of apomictic and non-apomictic genotypes are very important to be used as male or female parents in triploid mandarin breeding programs. These plants can also be regenerated by micrografting onto rootstock after treating with colchicine (Juarez *et al*., 2015).

Improvement in micrografting technique

Micrografting procedures are difficult and generally results in a low rate of successful grafts, which makes it an expensive and time-consuming production technique. It is due to the fact that more technical expertise is required in preparing successful grafts on small-scale material and handling difficulties associated with the preserving the delicate graft unions. In many experiments, failure rate for micrografts was higher than desired. *In vitro* grafts of fruit plants often fail due to incompatibility reaction, poor contact between stock and scion and phenolic browning of cut surfaces. In order to alleviate some of these limitations, different techniques have been developed to make micrografting a successful and superior technology for the benefit of technicians, researchers, nursery operators and commercial tissue culture laboratories.

1. Light or dark incubation treatments

Significant variations have been reported in the percentage of successful grafts upon exposure of seedling to light. Hamaraie *et al*. (2003) reported higher frequency of successful grafts (50%) in grape fruit seedlings were obtained from seeds germinated under continuous dark darkness for two weeks as compared to only 5% successful grafts with seedlings which developed under light.

2. Use of growth regulators

Growth regulators particularly cytokinins and auxins have been found effective for improving the graft success rate. These growth regulators increase the rate of cell division and improve callus formation, which in turn help in increasing the percentage of successful graft unions. Wang et al. (2010) found NAA effective in improving the micrograft success in walnut. Rafail and Mosleh (2010), reported increase in micrograft success from 30-90 % in pear and 40-90 % in apple with increasing BAP concentration from 0-2 mg/l.

3. Sucrose concentration of the medium

Sucrose concentration of nutrient medium had a significant effect on the percentage of successful grafts. Navarro *et al*. (1975) reported that sucrose concentration of medium of grafted plants played significant role and the highest rate of successful grafts in citrus species was obtained with 7.5 % sucrose. Generally *in vitro* growth and development increases with increased sugar concentration.

4. Preventing desiccation of the graft

Desiccation of graft or surfaces of the grafting partners is one of the major causes of graft union failure. To prevent this phenomenon, agar drops are usually used and obtained better graft success. Micrografts in which an agar drop was added to their grafted area were highly successful (70 % in apple and 60 % in pear) as compared to those without an agar drop (10 %). Adding an agar drop usually prevents scion drying and makes the transport of different materials possible and holds the graft units together until the fusion takes place.

5. Browning and tissue blackening

Exudation of phenolic compounds from the cut surfaces and their oxidation by polyphenoloxidase and peroxidase enzymes cause discolouration of the tissues which results in poor micrografting. Browning of the cut surfaces inhibits the growth and development of new cells and results in poor graft union. To block the oxidation phenomena and prevent tissue browning, various substances have been used which include thiourea, cysteine, chorohydrate (Jonard, 1986), citric and ascorbic acid (He *et al.*, 1979).

Kanwar and co-workers in 2019 studied the effect of auxins like NAA, IAA and 2,4-D on success of micrografting in Carrizo citrange and found that the maximum success of 56 % success obtained when 2,4-D used at 3 mg/l compared to other treatments (Figure 3).

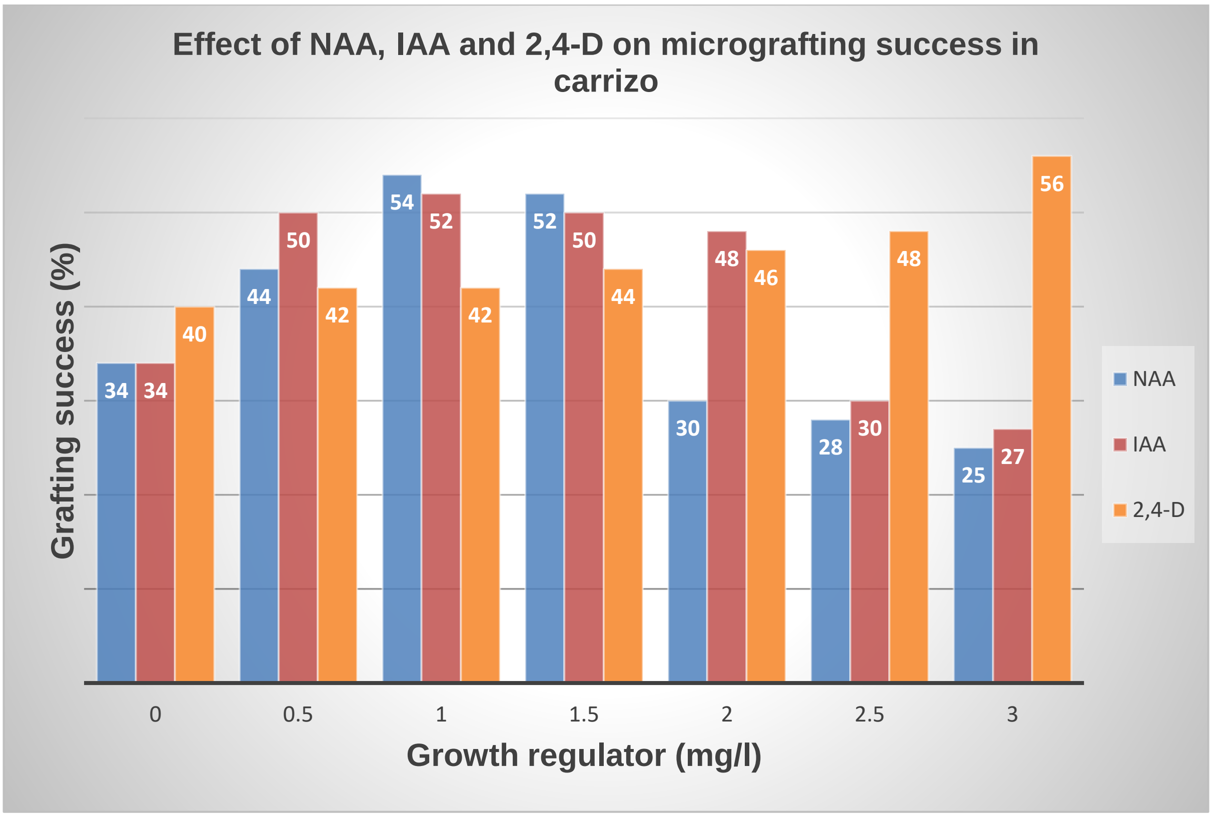

Fig. 3: Effect of NAA, IAA and 2,4-D on micrografting success in carrizo

Agustina and co-workers in 2020 conducted a study to know the effect of addition of BAP on shoot growth percentage in micrografts of mangosteen and found that BAP at 2 mg/l concentration was found effective which gave 86 % of shoot growth compared to 69 % of shoot growth at zero concentration. The results are depicted in Figure 4.

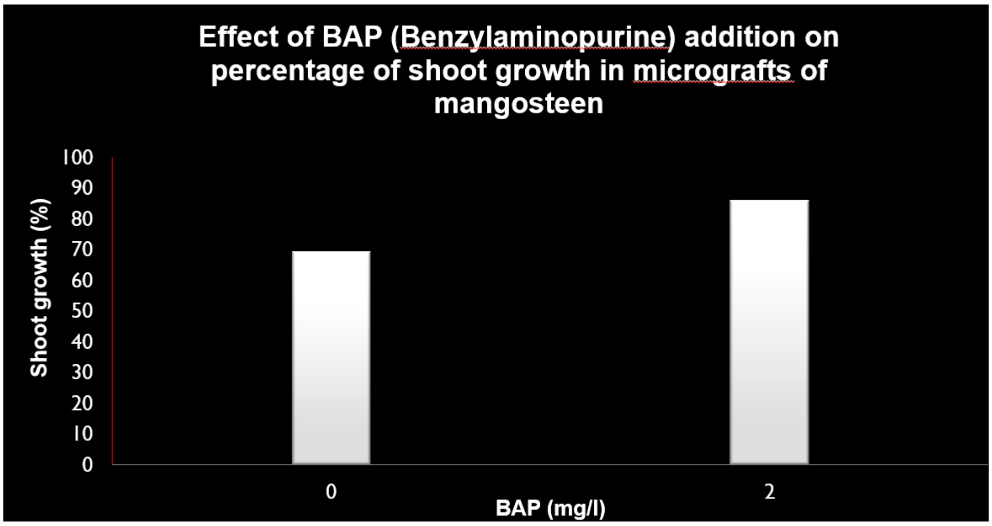

Fig. 4: Effect of BAP (Benzylaminopurine) addition on percentage of shoot growth in micrografts of mangosteen

Tabeei and co-workers in 2020 studied the effect of BA addition on meristem survival rate of pistachio and found that the BA at 1 mg/l concentration was found effective which gave 59 % of survival rate of meristem. The results are shown in Figure 5.

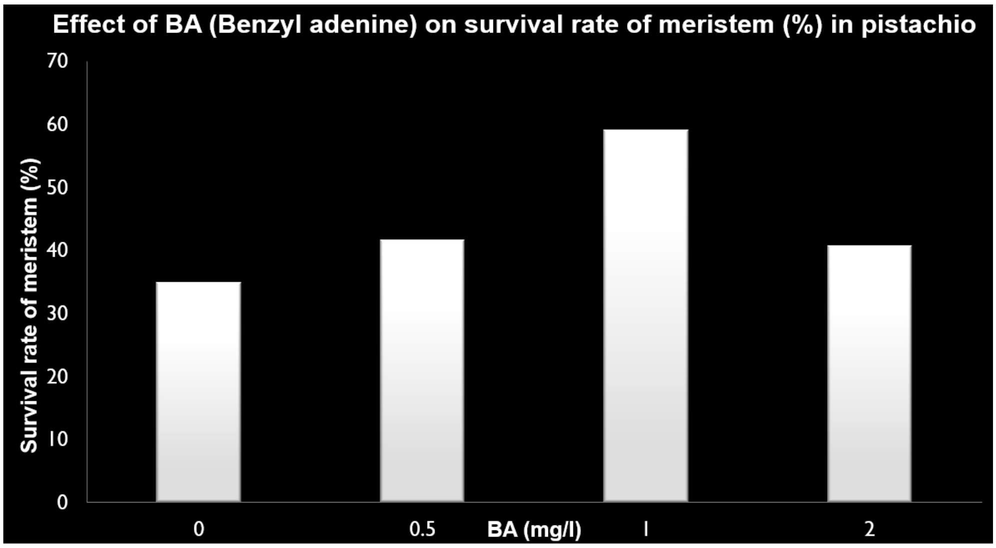

Fig. 5: Effect of BA (Benzyl adenine) on survival rate of meristem (%) in pistachio

Conclusion:

Micrografting has great potential for improvement of fruit plants and has been used for the production of virus and viroid-free plants in horticultural crops without the application of harmful pesticides. Besides it has also been used in prediction of incompatibility between the grafting partners, virus indexing, production of disease-free plants particularly resistant to soil borne pathogens, safe germplasm exchange between countries and multiplication of difficult to root plants. It is a safe *in vitro* technique, which can be utilized for commercial production of virus-free grafted plants with desired cultivars and suitable rootstock throughout the year under controlled conditions. Among various methods of grafting like vertical slit, wedge and horizontal method, vertical method was found most suitable in fruit crops. Successful micrografting protocols have been developed for various crops including citrus, apple, pistachio, pear, grape, olive *etc.*

Future avenues:

There is a need of development of well-defined protocol for *in vitro* raising of fruit plants where it is not yet reported. Standardization of culture and media for micropropagation and also there is a need to develop efficient grafting methods other than the existing methods which could give better grafting success.

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SEED QUALITY AS INFLUENCED BY SULPHUR FERTILIZATION IN GRAIN AMARANTH (*AMARANTHUS HYPOCHONDRIACUS* L.)

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Abstract:

A field experiment was conducted at Research and Extension Center, Gaja, College of Forestry, Ranichauri, Tehri Garhwal of VCSG Uttarakhand University of Horticulture and Forestry, Bharsar, Pauri Garhwal, Uttarakhand to investigate the response of sulphur fertilization on seed quality of grain amaranth. The experiment consisted of eight treatments comprising two varieties (Annapurna, PRA-3) and four fertilizer doses (RDF only, RDF + Sulphur @ 20 kg/ha, RDF + Sulphur @ 40 kg/ha and control) was laid out in Split Plot design with three replications under field conditions. The seed obtained from field after harvesting of crop were analyzed for estimating the seed quality parameters. On the basis of laboratory experiments, Annapurna performed well as compared to PRA-3 among both the varieties. Among various fertilizer doses, RDF + Sulphur @ 20 kg/ha showed significant results as compared to other fertilizer doses. Also, the interaction between varieties and fertilizer doses were found significant for quality parameters like electrical conductivity, speed of germination, mean daily germination, mean germination time, germination percent, seed vigour index I & II both for standard germination and cold test.

Keywords: *Amaranthus hypochondriacus* L., sulphur, seed quality, germination, cold test

Introduction:

Grain amaranth (*Amaranthus hypochondriacus* L.) called as pseudo cereal, is an under-exploited tropical crop with a high nutritive value. It belongs to the family *Amaranthaceae* and genus *Amaranthus.* The genus consists of 60 species of annual herbs, which are native of America, of which 25 species occur in India. There are four cultivated species of grain amaranth *viz*., *A. hypochondriacus* (L), *A. cruentus* (L), *A. caudatus* (L) and *A. edulies* (L). In India, *A. hypochondriacus* is known as the 'king grain' (Narwade and Pinto, 2018).

Grain amaranth has tremendous quality and rich in nutrients such as protein 14-19%, carbohydrates 62-66%, fibre 4-5%, fat 6-7%, 2.5-4.4% ash (Mlakar *et al,* 2009). Also, it is a rich source of essential amino acids (Ozsoy*et al*., 2009). Moreover, amaranth seed protein is rich in sulphur containing amino acids like lysine (4.9 to 6.1g/100 g protein) with high digestibility (approx. 90%) which is usually deficient in other conventional cereal grains (Joshi and Rana, 1991). It also complements raised levels of sulphur amino acid content (2-5%), which is greater than that measured in the most of legumes (1.4% on average), such as soybeans, peas and beans (Gorinstein and Moshe, 1991).

Also, among major plant nutrients, sulphur is recognized as the important nutrient in all the crops. Ideal sulphur fertilization in soil helps in plant growth and development and also improves utilization of other nutrients (Skwierawska *et al.,* 2008). Ja¨rvan *et al*. (2012) found that severe sulphur deficiency occurring during the early growth stages of winter cereals caused an irreversible reduction of generative yield components, and the grain yield. Such severe disorder could only be balanced by sulphur fertilization prior to tillering. Also, the nutritional status of sulphur had the strongest effect on the number of grains per ear. The effect of sulphur addition had relevance when nitrogen was not a limiting factor, showing a positive interaction between these two nutrients on crop growth, reflected in higher nitrogen use efficiency (Salvagiotti and Miralles 2008). Hence this study was conducted to investigate the response of sulphur fertilization on seed quality of grain amaranth.

Material and Methods:

The investigation was conducted during *kharif* season of 2018-19 at Research and Extension Center, Gaja, College of Forestry, Ranichauri, Tehri Garhwal of VCSG Uttarakhand University of Horticulture and Forestry, Bharsar, Pauri Garhwal, Uttarakhand at 30°26 N latitude and 78°41 E longitudes to investigate the response of sulphur fertilization on seed quality of grain amaranth. The experiment consisted of eight treatments comprising two varieties (Annapurna, PRA-3) and four fertilizer doses (RDF only, RDF + Sulphur @ 20 kg/ha, RDF + Sulphur @ 40 kg/ha and control). The experiment was laid out in Split Plot design with three replications under field conditions and two factor CRD in lab conditions. Various seed quality parameters were tested as discussed below.

Seed moisture content (%)

For estimating moisture content, the seeds were dried in an electric oven at 130°C for 1 hour. Moisture content of seeds was determined by the following formula given by Evans (1972):

$$\text{Moisture content} = \frac{\text{Fresh weight} - \text{Oven dry weight}}{\text{Fresh weight}} \text{ X } 100$$

Electrical conductivity (µS/cm)

The seeds were treated with 0.1% HgCl and then placed in a test tubes then test tube was filled with distilled water 5ml each then it was placed in BOD incubator at 24°C for 24 hrs. After that seed leachate was separated, then with the help of electrical conductivity meter reading was recorded.

Speed of germination (%)

Four replications of 100 seeds were taken from each treatment and placed in top up paper (T.P) media and then kept at 25°C in germinator. After the seed began to germinate, they were checked daily at approximately the same time each day. Normal seedlings were removed from the test when they reached a predetermined size. This procedure was continued until all the seed that were capable of producing a normal seedling had germinated. An index was computed for each treatment by dividing the number of normal seedling removed each day by the corresponding day of counting (Devagiri, 1998).

Mean daily germination (%)

For mean daily germination (per cent), following formula was used for evaluation given by Czabator (1962).

$$\text{MDG} = \frac{\text{Final germination \%}}{\text{Total number of days in test}}$$

Mean germination time

For the calculation of mean germination time, following equation of Ellis and Roberts (1981) was used as under:

$$\text{MGT} = \sum \frac{\text{Dn}}{\text{n}}$$

Where, n is the number of seed which was germinated on day 'D', and D is the number of days counted from the very beginning of germination.

Standard germination (%)

Four random samples of every treatment were taken, each replication being of 100 seeds. The seeds were kept in top up paper (T.P) and then placed in germination chamber at 25°C. Standard germination per cent (final count) were recorded for normal seedlings 8th day and expressed in terms of percentage.

Seed vigour index

The seedling vigour index was calculated by two different methods (Abdul Baki and Anderson, 1973).

- **Seed vigour index I**

  The seedling vigour index I was calculated as per the following formula:

  SVI- I = Standard germination (%) X Seedling length (cm)

- **Seed vigour index II**

  The seedling vigour index II was calculated as per the following formula:

  SVI- II = Standard germination (%) X Seedling dry weight (g)

Cold test

Four random samples of every treatment were taken, each replication being of 100 seeds. The seeds were kept in petri-dishes and then placed in refrigerator at 10°C for 7 days. After 7 days, the petri-dishes were transferred to normal conditions, *i.e.,* @ 25°C and incubated for 8 days. On the 8th day seedling length, seedling dry weight, seedling fresh weight, germination percentage were taken and seedling vigor index I and II was calculated (ISTA, 1995).

Result and Discussion:

Seed quality parameters like seed moisture content, electrical conductivity, speed of germination, mean daily germination and mean germination time presented in (Table 1) revealed significant effect of sulphur. Among the varieties, Annapurna performed well in terms of seed quality parameters. Electrical conductivity test is generally done to check the vigour of seed by detecting seed deterioration process since its early phase. Among the varieties, Annapurna was found significantly more vigorous as compared to PRA-3. While RDF with sulphur 40 kg/ha recorded minimum EC reading in comparison to other. PRA-3 losses high amount of seed leachate which shows the less vigorous nature of the seed. Also RDF with sulphur performed well in electrical conductivity test of seed might be due to sulphur that helps in maintaining the integrity of seed membrane systems which reduces the rate of seed leachate from seeds. Among the varieties, mean germination time did not differ significantly. While, among various fertilizer doses it differs significantly with increase in quantity of sulphur fertilizer, which might be due to late enzyme activation in seeds.

Table 1: Seed quality parameters as influenced by different varieties of amaranth and fertilizer doses

Treatments	Seed moisture content (%)	Electrical conductivity (µS/cm)	Speed of germination (%)	Mean daily germination	Mean germination time
Variety					
Annapurna	9.9	113.6	23.0	11.8	50.0
PRA-3	10.1	124.1	22.2	11.5	48.8
SEm±	0.1	1.4	0.2	0.1	0.4
CD (P = 0.05)	NS	4.1	0.5	0.2	NS
Fertilizer doses					
Control	10.3	132.4	22.4	11.3	46.7
RDF + Sulphur @ 20 kg/ha	9.5	102.9	22.7	11.8	50.3
RDF + Sulphur @ 40 kg/ha	10.3	96.5	22.8	12.0	50.2
RDF (60:40:20)	9.8	143.6	21.5	11.5	50.4
SEm±	0.1	2.1	0.2	0.1	0.6
CD (P = 0.05)	0.4	5.8	0.7	0.2	1.7
Interaction	NS	8.2	1.0	0.4	2.4

RDF with sulphur @ 40 kg/ha recorded significantly higher speed of germination, which is an oldest concept of seed vigour. There is positive correlation between seed vigour index and speed of germination (Kumar, 2017).

Maximum mean daily germination was recorded with RDF + Sulphur 40 kg/ha. This might be due to sulphur amplified protein content in amaranth seed which leads to higher germination caused by enhanced metabolism and their activity, which stimulates embryonic growth during germination. Gallardo *et al.* (2002) also reported that, methionine synthase is basic components during switching from a dormant to a highly active metabolic state in the seed germination.

Among fertilizer doses, RDF + Sulphur @ 40 kg/ha recorded best in all aspects of standard germination % of grain amaranth (Table 2). Among the varieties, Annapurna performed well in terms of germination % as compared to PRA-3. Among various fertilizer doses, RDF with sulphur @ 40 kg/ha recorded significantly higher seed germination % and seed vigour index, which might be due to the secondary metabolites of sulphur such as methionine. It plays a vital role in synthesis of protein. S-Adenosyl methionine, ethylene and polyamine, all of these constituents are essential for germination % of seeds as well as seedlings growth and maximum sulphur dose resulted in significantly higher seedling vigour in comparison to control (Jahan *et al*., 2015).

Table 2: Standard germination and cold test as influenced by different varieties of amaranth and fertilizer doses

Treatments	Standard germination			Cold test		
	Germination (%)	Seed vigour index I	Seed vigour index II	Germination (%)	Seed vigour index I	Seed vigour index II
Variety						
Annapurna	94.6	568.1	0.48	94.0	689.4	0.43
PRA-3	91.6	577.4	0.43	91.6	732.9	0.43
SEm±	0.5	5.7	0.004	0.6	8.8	0.004
CD (P = 0.05)	1.4	NS	0.01	1.7	25.9	NS
Fertilizer doses						
Control	90.3	571.1	0.40	89.0	696.9	0.43
RDF + Sulphur @ 20 kg/ha	94.1	564.1	0.50	94.0	723.3	0.45
RDF + Sulphur @ 40 kg/ha	96.3	601.8	0.44	95.1	716.7	0.42
RDF (60:40:20)	91.6	553.9	0.46	93.0	707.7	0.43
SEm±	0.7	8.1	0.01	0.8	12.5	0.01
CD (P = 0.05)	2.0	23.8	0.02	2.4	NS	0.02
Interaction	2.8	33.6	0.03	NS	51.78	0.021

Among different varieties, Annapurna performed well in terms of germination % for cold test (Table 2) as compared to PRA-3. While among various fertilizer doses RDF with sulphur @ 40 kg/ha showed statistically at par result with RDF + Sulphur @ 20 kg/ha of germination % for cold test. In seed vigour index, among different varieties PRA-3 recorded significantly superior as compared to Annapurna and RDF with sulphur @ 20 kg/ha recorded significantly higher seed vigour index I and II being at par with RDF + Sulphur @ 40 kg/ha among various fertilizer doses. This might be due to familiar conditions for both the varieties, as both grown in the Himalaya region. So the seed of that particular crop can tolerate extreme cold condition. There was decrease in germination % in comparison to the standard germination which is due to extreme cold condition for the seed of *kharif* season.

Conclusion:

Based on the study, it can be concluded that application of 20 kg sulphur/ha along with RDF (60:40:20) enhances the seed quality of Annapurna of grain amaranth.

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A SCIENTOMETRIC REVIEW OF NPK FERTILIZER RESEARCH: VISUALIZATION AND ANALYSIS

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Abstract:

In this area, there is a scope to analyze the bulk of the research output available which could be categorized to decide the next steps and identify research gaps. Therefore, the scientometric approach was carried out in this study, by Biblioshiny and VOSviewer to identify the trends and problems associated in this research area. Based on a Web of Science database search, 2943 documents were retrieved for NPK fertilizer from Web of Science Core Collection and they were systematically screened out from 2013 to 2022. The documents were reviewed for co-authorship, collaboration with nations, co-occurrence of keywords, and institutional collaboration. The data showed that the studies released had an upward trend over the years. China plays an important role in the research area of NPK fertilizer development among the developing countries by taking into account the number of citations. Developed countries have also played a significant role in promoting the research in this field, along with developing countries. In this study, an extensive analysis of the status of research and developments in NPK fertilizer is provided along with the feedback on possible research directions.

Keywords: NPK Fertilizers, VOS viewer, Agricultural Analysis

Introduction:

Fertilizers are substances that can be in a solid, liquid, or gaseous state and contain one or more plant nutrients. They can be applied to the soil, or directly on the plant to maintain or increase fertility to produce crops with good quality. They supplement naturally available nutrients in the soil and also provide additional nutrients that are required for specific types of crops (spglobal.com). In general, Fertilizers are defined as "Any material, organic or inorganic, natural or synthetic, that supplies one or more of the chemical elements required for the plant growth." In most fertilizers, NPK are the main ingredients. The letters NPK stand for the three major nutrients that plants need to live and grow – nitrogen, phosphorus, and potassium.

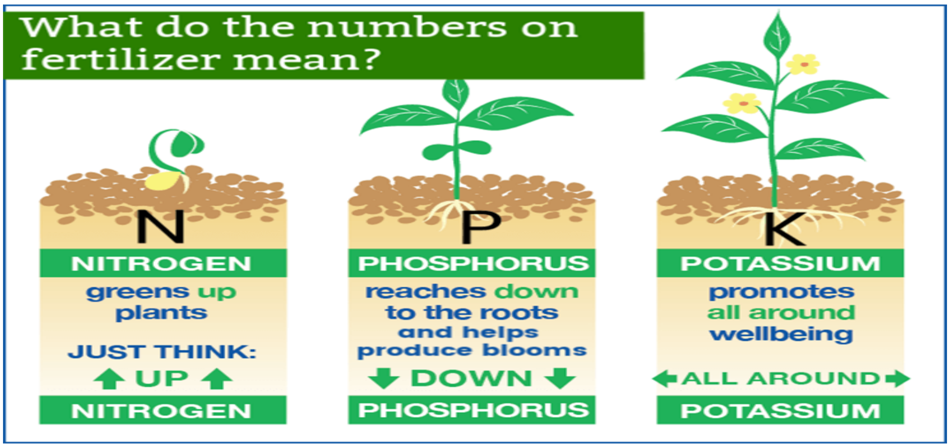

Fig. 1: Role of NPK fertilizer

NPK fertilizer is usually used to increase the growth of a plant. Amino acids (proteins), nucleic acids, nucleotides, and chlorophyll in plants are prepared by the N element in NPK fertilizer. The element P in the NPK fertilizer has a function as a storage and energy transfer. A hundred years ago, two German chemists, Fritz Haber and Carl Bosch, devised a way to transform nitrogen in the air into fertiliser, using what became known as the Haber-Bosch process. These three minerals are often deficient in the soil in which plants grow, supplying them as a fertiliser helps plants thrive.

Formula & preparation of NPK fertilizer:

A fertilizer with an NPK ratio of 2-1-1 or 3-1-1 works for most trees and shrubs. The "3" in the ratio represents the amount of nitrogen, which promotes leaf growth, and the "1" represents the amount of phosphorus and potassium which are essential for root development and overall health. It is also represented as NPK 20:10:10, NPK 15:15:15, NPK 20:20:20, NPK 11:46:14, NPK 6:13:46, NPK 30:10:10. The prepared solution is filtered and the calcium carbonate crystals are removed and used for the production of granular calcium ammonium nitrate fertilizer. The resulting dilute ammonium nitrate solution is concentrated and also used to produce calcium ammonium nitrate fertilizer or NPK.

A distinct advantage of compounded NPK fertilizers is that they can be formulated based on the type of crop and soil. When compounded into other materials they are less soluble in groundwater. This makes them suitable for dry soil matrices and areas prone to droughts. Fertilizer products can be used in various physical and chemical forms. Based on its state, each form has its own advantages and limitations. NPK is typically used for sugar beets, sunflower, and buckwheat during the autumn and for corn, wheat, barley, and vegetable crops during spring (Oluwaseyi *et al.,* 2022).

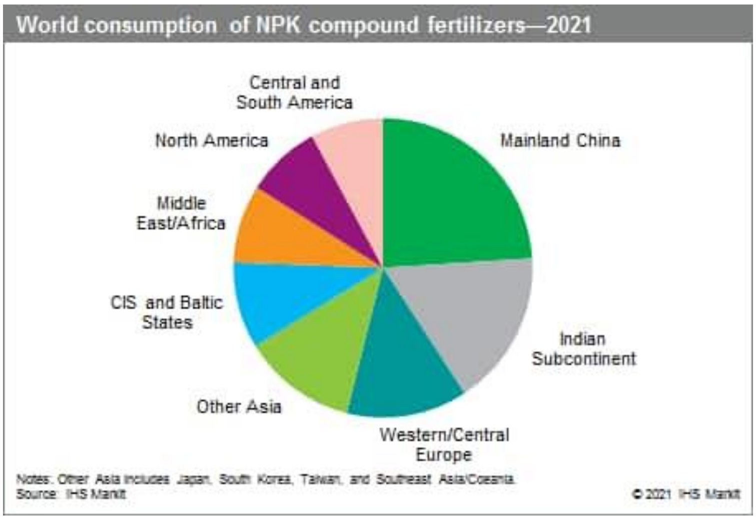

Fig. 2: Production of NPK –World wide

Mainland China has become the world's largest producer and consumer of NPK compound fertilizers. Over 3,000 companies produce NPK compound fertilizers in mainland China, with a total capacity of about 173.5 million metric tons in 2021. Most of the consumption growth will be in Africa (albeit from a small base), the CIS and Baltic States, the Middle East, and Southeast Asia/Oceania.

Demand for fertilizers is driven by the need for food, which in turn is driven by the size and wealth of the population. The global population has doubled from about 3 billion in the early 1960s to around 6 billion by the turn of this century. Between now and 2050, the population is expected to increase by another 3 billion, equivalent to the current combined population of mainland China and South Asia. Feeding a population of 9 billion people in 2050 will involve a combination of several developments, including relying on increased plant nutrition, new technologies, and the cultivation of more marginal land. Food production has increased substantially over the past several decades, in part because of increasing yields as a result of fertilizer application.

Scientometrics is the science of measuring the "quality" of science. It is often done using biblimetrics which is a measurement of the impact of scientometric publication. It includes all quantitative aspects of the science, communication in science and science policy. The term scientometrics originated as a Russsian term for the application of quantitative methods to the history of science. It deals with analysis, evaluation and graphic representation of science and technology. Mathematics contains an area of knowledge that includes the topics of numbers, formula and related structures of the shapes.

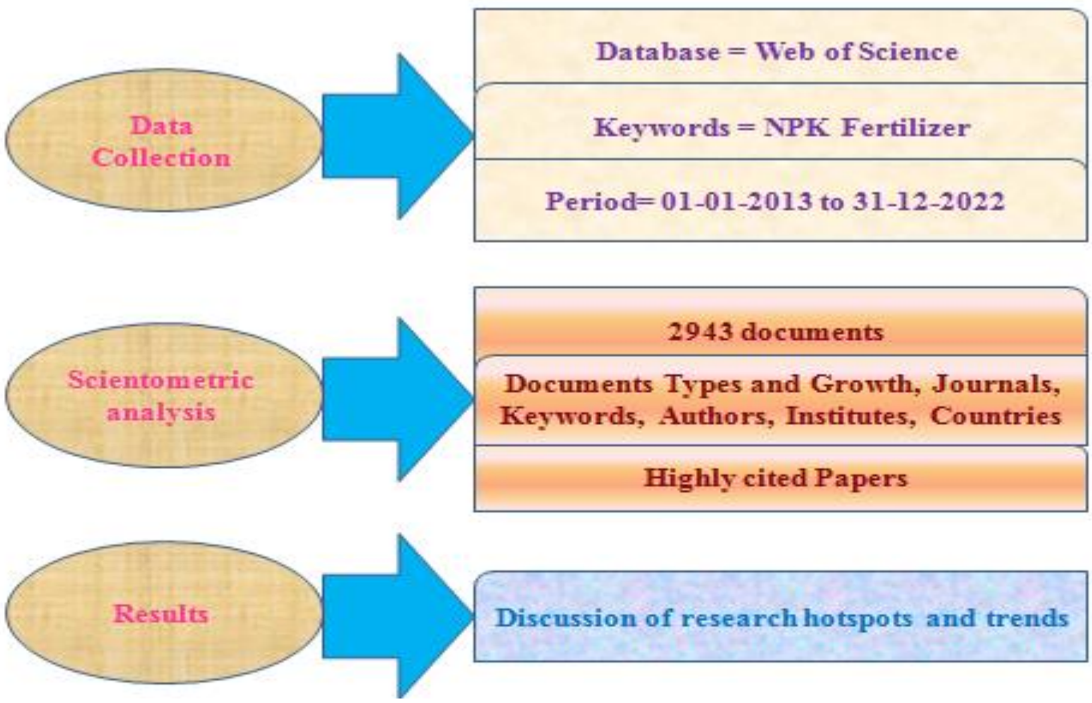

Fig. 3: Flowchat of Research work

Methodology (Data collection and processing)

The experiment dataset comes from the abstract and citation databases such as the Scopus (http://www.scopus.com) and the web of science http://www.webofknowledge.com). These databases are the most common and well-known data sources for bibliometric studies. Data collection was the first step, which needed a suitable database to extract scientific publications from the Web of Science database. It was adopted to collect bibliographic information from works on NPK fertilizer published between 2013 and 2022. In the current study, the Web of Science collection's advance search mode was used with the keywords search topic "NPK fertilizer". To confirm the accuracy of the data extracted, the database was carefully checked. These extracted documents were processed using VoSviewer, and Biblioshiny scientometric software after being exported as "plain text" from the Web of Science database. It provides an overview of the body of published literature, publication years in the given topic. Major contributing nations, organisations, journals, and author keywords are displayed by VoSviewer. The productivity of authors as well as the impact factors of their authors are visualised by Biblioshiny. 2943 publications in all have been pulled from the WoS database, and the data has been analysed using several software programmes.

Table 1: Main Information about Data

Description	Results
Timespan	2013 to 2022
Documents	2943
Average years from publication	4.44
Average citations per documents	15.36
Average citations per year per documents	2.734
References	91440
AUTHORS	
Authors	10002
Authors of single-authored documents	48
Authors of multi-authored documents	9954
AUTHORS COLLABORATION	
Documents per Author	0.294
Authors per Document	3.4
Co-Authors per Documents	5.65
Collaboration Index	3.45

Table 1 represents the brief profile of NPK fertilizer were seen through the Biblioshiny from the period 2013-2022. For Article had appeared in 2943 Documents, 4.44 Average years from publication, 15.36 Average citations per documents, 2.734 Average citations per year per documents and 91440 References. 10002 authors wrote 48 single-authored documents, 9954 multi-authored documents. With a collaboration index of 3.45, Document per author 0.294, Author per documets 3.4 and co-authors per documents 5.65.

Table 2 Figure 4 presents the annual scientific production of NPK fertilizer research by year, number of yearly publications from 2013 to 2022. The research articles are gradually increasing trend in the study period. The quantity of research articles published from 2013 to 2022. The study shows that the highest numbers of 525 research articles are published in the year 2022. The lowest number of 156 research articles is published in the year 2013.

Table 2: Annual Production of NPK fertilizer

Year	Articles	Percentage
2013	159	5.4
2014	188	6.39
2015	209	7.1
2016	219	7.44
2017	235	7.99
2018	291	9.89
2019	336	11.42
2020	355	12.06
2021	426	14.47
2022	525	17.84
	2943	100

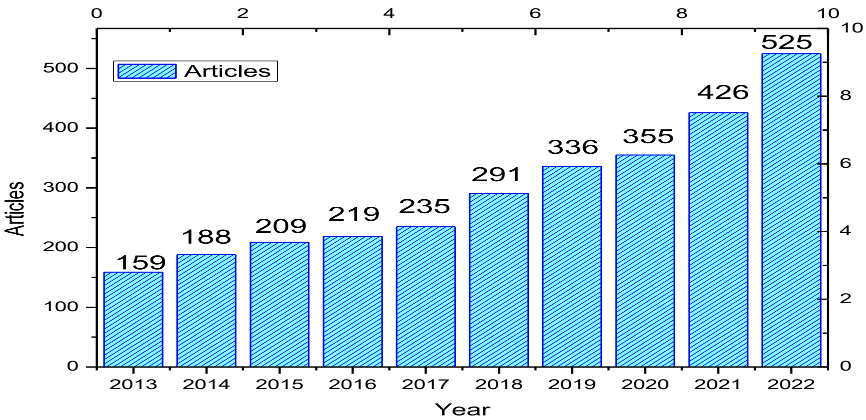

Fig. 4: Annual Productivity

The VOS viewer visualizations for the direct citation relationships between countries for the periods 2013-2022 appear in Figure 3. Clusters were limited to a minimum of five members. Each country appearing in the figure met a minimum productivity threshold of five publications for the time period investigated. However, the smaller the node, the less likely it is that there is a connection with other countries. It was used to identify the most contributing countries in the development of NPK Fertilizer. As can be observed from Table 3 and Figure 3, Peoples china (882 documents, 21130 citations) is leading in terms of publications released followed by the India (605 documents, 6471 citations), USA (203 documents, 4725 citations), Pakistan (181 documents, 1783 citations), Brazil (153 documents, 1445 citations), Poland (143 documents, 1432 citations) and Germany (100 documents, 2244 citations) occupied the next ranks in the number of publications.

Table 3: Top 10 Highly productive Countries

Rank	Countries	Documents	Citations
1	Peoples Republic of china	882	21130
2	India	605	6471
3	USA	203	4725
4	Pakistan	181	1783
5	Brazil	153	1445
6	Poland	143	1432
7	Germany	100	2244
8	Australia	90	2743
9	Egypt	83	1112
10	Nigeria	79	1026

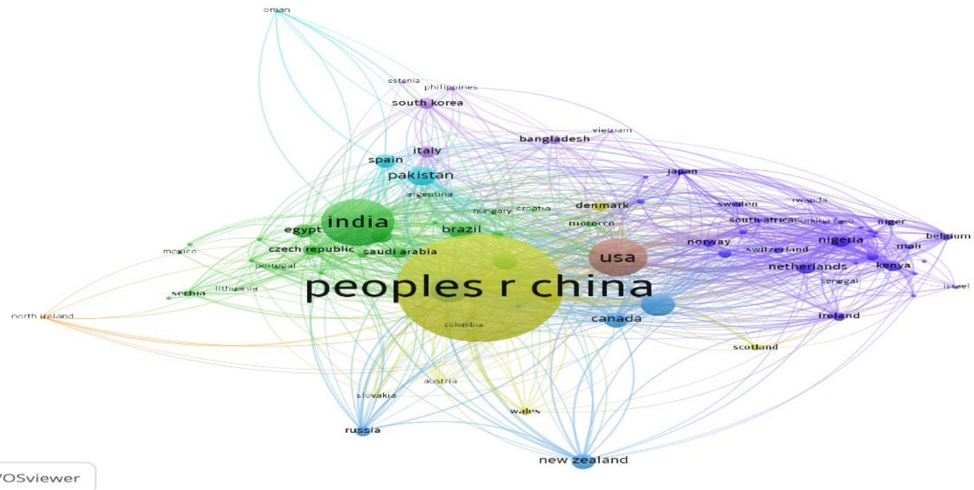

Fig. 5: Network Visualization Countries

Table 4 and Figure 6 represents the information of Institutions in which the articles in the field of NPK Fertilizer. These were calculated using the VoS Viewer software. Regarding the citation count, The Institutions "Chinese Acad Sci" holds the first rank published 264 research papers with 8511 citation. The "Chinese Acad Agr Sci" holds the second rank published 207 research papers. The "Univ Chinese Acad Sci" holds the third rank published 100 research papers. The "Univ Agr Faisalabad" holds the forth rank published 64 research papers. The "Northwest A&F Univ" holds the fifth rank published 55 research papers. The "Nanjing Agr Univ" holds the sixth rank published 54 research papers. The "Icar Indian Agr Res Inst" holds the seventh rank published 53 research papers and etc.,

Table 4: Top 10 Highly productive Institutions

Rank	Institution	Documents	Citations
1	Chinese Acad Sci	264	8511
2	Chinese Acad Agr Sci	207	6109
3	Univ Chinese Acad Sci	100	3129
4	Univ Agr Faisalabad	64	792
5	Northwest A&F Univ	55	1469
6	Nanjing Agr Univ	54	1682
7	Icar Indian Agr Res Inst	53	509
8	Huazhong Agr Univ	46	870
9	Jilin Acad Agr Sci	46	1427
10	China Agr Univ	41	791

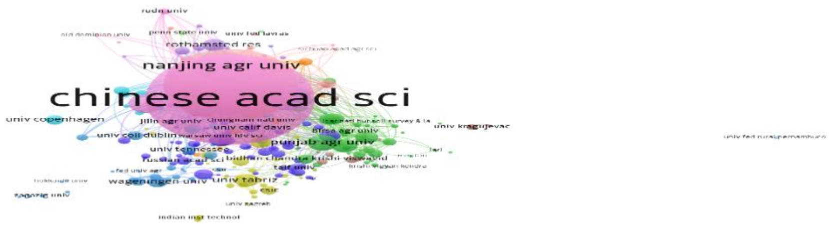

Fig. 6: Network Visualization Institutions

Table 5: Top 10 Highly productive Journals

Rank	Journals	Documents	Citations
1	Agronomy-basel	118	1027
2	Communications in soil science and plant analysis	116	907
3	Journal of plant nutrition	104	658
4	Indian journal of agricultural sciences	93	138
5	Science of the total environment	77	2744
6	Archives of agronomy and soil science	69	585
7	Soil & tillage research	56	2635
8	Applied soil ecology	54	1860
9	Sustainability	54	434
10	Journal of soils and sediments	49	1173

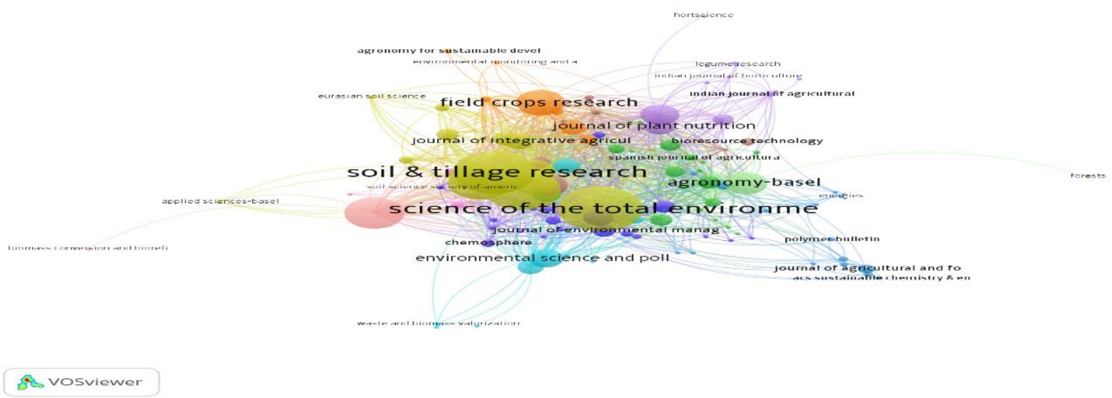

Fig. 7: Network Visualization Journals

Table 5 and Figure 7 represents the information of journals in which the articles in the field of NPK fertilizer. These were calculated using the VoS Viewer software. Regarding the citation count, The journal "Agronomy-basel" holds the first rank published 118 research papers with 1027 citation. The "Communications in soil science and plant analysis" holds the second rank published 116 research papers. The "Journal of plant nutrition" holds the third rank published 104 research papers. The "Indian journal of agricultural sciences" holds the forth rank published 93 research papers. The "Science of the total environment" the fifth rank published 77 research papers. The "Archives of agronomy and soil science" holds the sixth rank published 69 research papers. The "Soil & tillage research" the seventh rank published 56 research papers. The "Applied soil ecology" holds the Eighth rank and the institution published 54 research papers. The "Sustainability" holds the Ninth rank published 54 research papers and The "Journal of soils and sediments" holds the tenth rank published 49 research papers.

Table 6: Top 10 Highly productive Author Impacts

Rank	Authors	h_index	g_index	m_index	Articles	Citation
1	Xu MG	28	46	2.545	52	2210
2	Wang BR	20	28	1.818	28	1247
3	Zhang JB	18	28	1.636	28	1008
4	Zhu P	18	35	1.636	35	1278
5	Kumar A	17	32	1.545	35	1071
6	Zhang WJ	17	33	1.545	35	1154
7	Shen QR	16	22	1.455	22	961
8	Ding WX	15	23	1.364	23	945
9	Sun N	15	18	1.364	18	675
10	Zhang HM	15	27	1.364	29	748

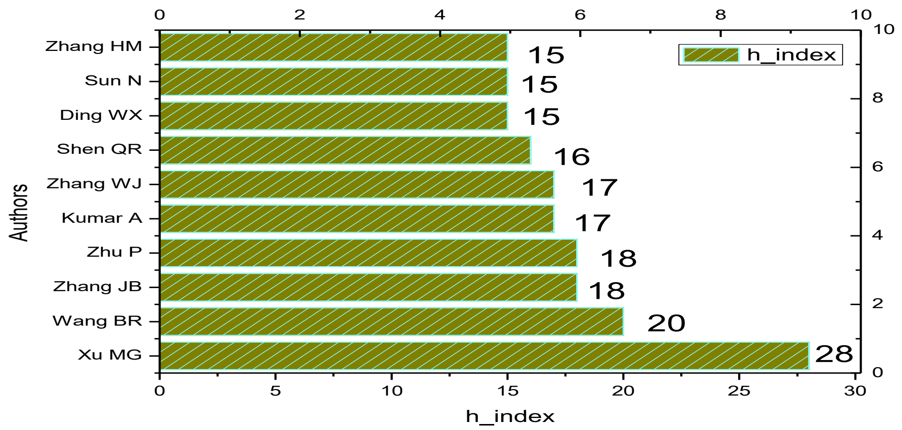

Fig. 8: Authors h-index

Table 6 presented the top 10 Author impact with numbers of literature published on NPK fertilizer. They were only highlighted author impact shows that, Xu MG rank the highest with 52 Articles (2210 Citation, 28 h-index and 46 g-index) literature published, followed by Wang BR 20 h-index, Zhang JB 18 h-index, Zhu P 18 h-index, Kumar A 17 h-index, Zhang WJ 17 h-index, Shen QR 16 h-index, Ding WX 15 h-index, Sun N 15 h-index and Zhang HM 15 h-index.

Table 7: Top 10 Highly productive Keywords

Rank	Keywords	Occurrences
1	Yield	176
2	Long-term fertilization	140
3	Fertilization	134
4	Fertilizer	113
5	Soil fertility	94
6	NPK	93
7	Biochar	91
8	Soil organic carbon	78
9	Manure	75
10	Maize	73

Figure 7 shows that Author keywords provide an indication of the prevalence of topics addressed by research. How they co-occur provides a further indication of their mutual relationships. The number of author keywords generated for each period is too large to display the complete vocabulary. Maps generated for the author keywords were limited to, approximately, the 100 most frequently occurring keywords by providing a frequency threshold for their inclusion in the map. Table 5 For the period 2013–2022, Yield is the 1st rank in the keywords with 176 occurance followed by Long-term fertilization,

Fertilization, Fertilizer, Soil fertility, NPK, Biochar, Soil organic carbon, Manure and Maize etc.

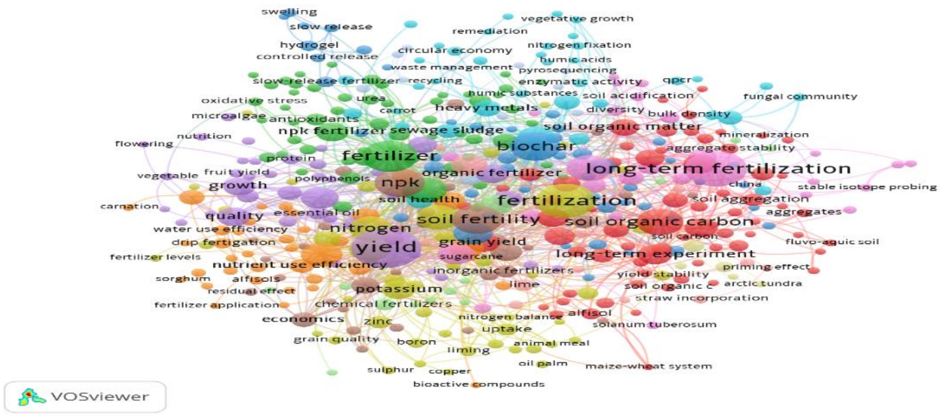

Fig. 9: Network Visualization Keywords

Sun *et al.* (2015) studied the 454 pyrosequencing of 16S rRNA gene when employed to compare the bacterial community structure among soils that had been subjected to 30 years of NPK fertilization under six treatment regimes: non-fertilization control, fertilization only, and fertilization combined with the use of pig manure, cow manure or low- and high-level of wheat straws. Consistent with expectation, long-term application of NPK chemical fertilizers caused a significant decrease of bacterial diversity in terms of species richness (i.e. number of unique operational taxonomic units (OTU)), Faith's index of phylogenetic diversity and Chao 1 index. Incorporation of wheat straw into soil produced little effects on bacterial community, whereas addition of either pig manure or cow manure restored bacterial diversity to levels that are comparable to that of the non-fertilization control. Moreover, bacterial abundance determined by quantitative PCR was positively correlated with the nutritional status of the soil (e.g., nitrate, total nitrogen, total carbon, available phosphorus); however, bacterial diversity was predominantly determined by soil pH.

Beesley *et al.* (2013) worked in the Arsenic (As) concentrations in soil, soil pore water and plant tissues were evaluated in a pot experiment following the transplantation of tomato (Solanumlycopersicum L.) plantlets to a heavily As contaminated mine soil (~6000 mg kg−1 pseudo-total As) receiving an orchard prune residue biochar amendment, with and without NPK fertiliser. An in-vitro test was also performed to establish if tomato seeds were able to germinate in various proportions of biochar added to nutrient solution (MS). Biochar significantly increased arsenic concentrations in pore water (500 µg L−1 –2000 µg L−1) whilst root and shoot concentrations were significantly reduced compared to the control without biochar. Fruit As concentrations were very low (b3 µg kg−1), indicating minimal toxicity and transfer risk. Fertilisation was required to significantly increase plant biomass above the control after biochar addition whilst plants transplanted to biochar only were heavily stunted and chlorotic. Given that increasing the amount of biochar added to nutrient solution in-vitro reduced seed germination by up to 40%, a lack of balanced nutrient provision from biocharcould be concluded. In summary, solubility and mobility of As were increased by biochar addition to this soil, but uptake to plant was reduced, and toxicity-transfer risk was negligible.

Table 8: Top 5 Highly cited Articles

Rank	Authors	Article Title	Source Title	Times Cited
1	Sun *et al.* (2015)	Bacterial diversity in soils subjected to long-term chemical fertilization can be more stably maintained with the addition of livestock manure than wheat straw	Soil biology & biochemistry	469
2	Beesley *et al.* (2013)	Biochar addition to an arsenic contaminated soil increases arsenic concentrations in the pore water but reduces uptake to tomato plants (Solanum lycopersicum L.)	Science of the total environment	191
3	Cui *et al.* (2013)	Long-term organic and inorganic fertilization alters temperature sensitivity of potential N2O emissions and associated microbes	Soil biology & biochemistry	188
4	(Cai *et al.* (2019)	Manure acts as a better fertilizer for increasing crop yields than synthetic fertilizer does by improving soil fertility	Soil & tillage research	170
5	Tian *et al.* (2016)	Biochar affects soil organic matter cycling and microbial functions but does not alter microbial community structure in a paddy soil	Science of the total environment	170

Cui *et al.* (2016) commended that the temperature sensitivity of N2O emissions, as measured by Q10 values (fractional change in rate with a 10°C increase in temperature), was higher in soils receiving long-term fertilizer addition compared with control. The abundance of archaeal amoA gene copies increased under all fertilizer treatments, but that of bacterial amoA only increased under mineral (NPK) fertilization. The increment of nirS, nirK and nosZ, under OM and MNPK fertilization by the T-RFLP analyses showed that both ammonia oxidizing and denitrifier community structures were altered by fertilization, but only the nirS community structure was sensitive to temperature change. Furthermore, a strong correlation was observed between nirS gene abundance and potential N_2O emissions. Relationships between AOA, nirK gene abundances and potential N_2O emission were significant but relatively weak. PLS path model revealed that besides direct effect, potential N_2O emission was also indirectly influenced by temperature through mediation of NH_4 þ concentration and nirS-type denitrifier. Our work suggests that warming-induced elevation of potential N_2O emission could be strengthened by long-term application of fertilizers, especially organic manure, via shifting community abundance and structure of nirStype denitrifier.

Cai *et al.* (2019) Chosed that, seven treatments were chosen: CK (nonfertilizer); N (synthetic nitrogen); NP (synthetic N and phosphorus); NPK (synthetic N, P and potassium); NPKM1 (synthetic NPK with manure); 1.5NPKM1 (1.5 times of NPKM1); and M2 (manure alone). He planned his work with the available data from a 25-year fertilization experiment in the humid subtropical region of Southern China were used to evaluate and quantify the effect of fertilization on crop yields via soil fertility. His research group findings were, the crop yields of wheat and maize under manure (1.36–1.58 and 3.85-5.82 Mg ha−1) were higher than those under CK (0.34 and 0.25 Mg ha−1) and synthetic fertilized treatments (0.27–0.97 and 0.48–2.65 Mg ha−1), as the averaged of 1991–2015. Higher SOC stocks were found under the NPKM1, 1.5NPKM1, and M2 treatments with a pronounced increase in SOC over the first 10 years and stable over the last 15 years. By the boosted regression trees, manure, synthetic fertilizer and soil properties (SOC storage, soil pH, and soil nutrients) accounted for 39%, 21%, and 40% of the variation of the relative yield, respectively. The results suggest that manure application is a viable strategy for regulating crop yields due to its improvement in soil fertility.

Tian *et al.* (2016) investigated the SOM in physical and chemical fractions, microbial community structure (using phospholipid fatty acid analysis, PLFA) and functions (by analyzing enzymes involved in C and N cycling and Biolog) in a 6-year field experiment with BC and NPK amendment. BC application increased total soil C and particulate organic C for 47.4–50.4% and 63.7–74.6%, respectively. The effects of BC on the microbial community and C-cycling enzymes were dependent on fertilization. Addition of BC alone did not change the microbial community compared with the control, but altered the microbial community structure in conjunction with NPK fertilization. SOM fractions accounted for 55% of the variance in the PLFA-related microbial community structure. The particulate organic N explained the largest variation in the microbial community structure. Microbial metabolic activity strongly increased after BC addition, particularly the utilization of amino acids and amines due to anincrease in the activity of proteolytic (L-leucine aminopeptidase) enzymes. The results indicate that microorganisms start to mine N from the SOM to compensate for high C:N ratios after BC application, which consequently accelerate cycling of stable N.

Conclusion:

The present work explores the characteristics of NPK Fertilizer literature from 2013 to 2022 based on the database of Web of Science (WoS) and its implication using the scientometric techniques. There is a large quantity of research conducted surrounding NPK Fertilizer, as shown from the productivity graphs developed with adsorbent technologies leading the way in terms of quantity, in both articles and citations. This high productivity includes high quality papers with the top ten overall authors displaying high h-index, g-index, and m-index, each category scoring over one highlighting successful research. High quantities of citations, again, show the high-quality articles published within the scientometric data. It was performed to visualize panorama of publications, the most prominent authors, institutions, countries, research categories, and journals. These indicators are intended to facilitate researchers in analysis of existing literature which could improve the research direction for better scientific contribution. Peoples Republic of China and India are the two biggest contributing countries on NPK Fertilizer effluents literature. The multiple authors contribution is highest and solo author is lowest contribution in the field of NPK Fertilizer. These indicators are intended to facilitate researchers in analysis of existing literature which could improve the research direction for better scientific contribution.

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INTEGRATED PEST MANAGEMENT OF *HELICOVERPA ARMIGERA* IN SOYBEAN CROP

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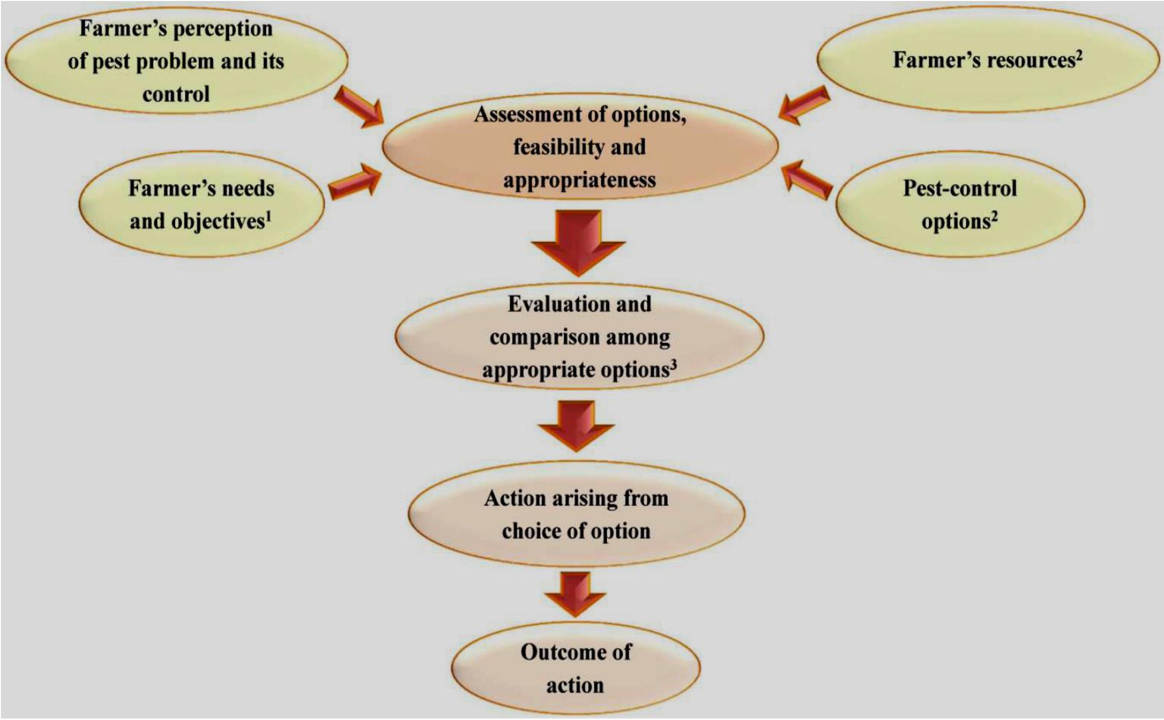
Introduction:

One of the most significant and frequently cultivated oil seed crops in the world is the soybean (*Glycine max* (L.) Merrill). The prevalence of various insect pests, including *Etiella zinkienella* Treitschke, *Tetranychus urticae* Koch, *Thrips tabaci* Lindeman, *Spodoptera exigua* (Hubner), and *Helicoverpa armigera* (Hubner), hinders successful production in soybean cropping systems (Naseri *et al.,* 2009). *Helicoverpa armigera* is an important pest of many crops in many parts of the world and is reported to attack more than 60 plant species belonging to more than 47 families. The pest status of this species can be derived from its four life history characteristics (polyphagy, high mobility, high fecundity and a facultative diapause) that enable it to survive in unstable habitats and adapt to seasonal changes. In order to increase the quality and quantity of soybean production in cropping systems for this oil seed crop, many strategies have been used to suppress *H. armigera*. However, synthetic pesticides such as synthetic pyrethroids, synthetic organophosphates, and bio rational chemicals are the primary means of containing *H. armigera* over the globe. This Environmental concerns over the widespread use of pesticides have periodically resulted in the creation of this pest's chemical resistance. International interest in integrated pest management (IPM) programs has increased due to the general trend away from using synthetic pesticides to control insect pests in agriculture, forestry, and human health. The element of sustainable agriculture is IPM (Kogan, 1998). IPM not only contributes to the sustainability of agriculture, it also serves as a model for the practical application of ecological theory and provides a paradigm for the development of other agricultural system components. The concept of IPM is becoming a practicable and acceptable approach among the entomologists in recent past all over the world and focuses on the history, concepts, and the integration of available control methods into integrated programmes.

However, this approach advocates an integration of all possible or at least some of the known natural means of control with or without insecticides so that the best pest management in terms of economics and maintenance of pest population below economic injury level (EIL) is achieved. Although the past research focused on developing various pest management tactics that would be packaged into an integrated pest management strategy, we have selected several types of resources for our discussions, realizing that there are other resources can be used in developing IPM programmes. Furthermore, to generate a comprehensive management programme, we present our perspectives on future research needs and directions for sustainable management of this pest in soybean cropping systems such as tri-trophic interactions, importance of modeling of insect population, crucial role of forecasting and monitoring programmes in IPM, interactions among different management tactics in IPM and significance of biotechnology and genetically modified plants in IPM.

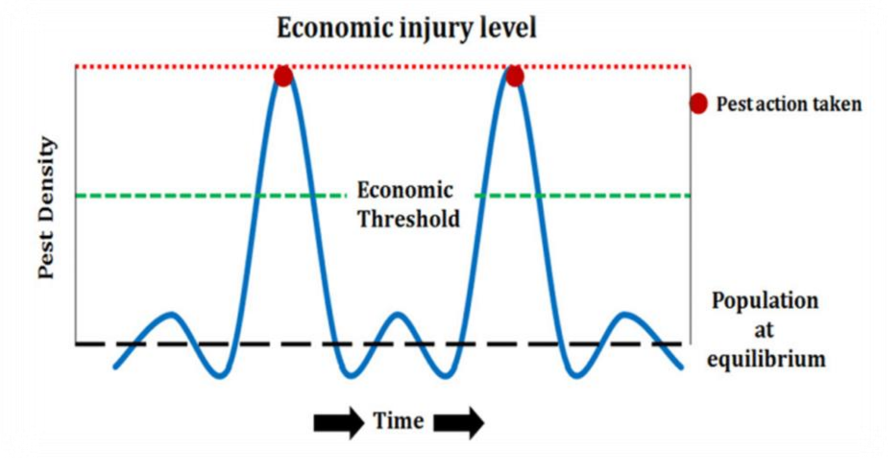

Decision Making Regarding IPM practises

Pest management is a combination of processes that include obtaining the information, decision making and taking action. In assessing, evaluating and choosing a particular pest control option, farmer's perception of the problem and of potential solutions is the most important factor. Decision making in pest management, like other economic problems in agriculture, involves allocating scarce resources to meet food demand of a growing population. In this process, agricultural producers have to make choices regarding the use of several inputs including labour, insecticides, herbicides, fungicides, and consulting expenses related to the level and intensity of pest infestation and the timing of treatment.



EIL and ET

EIL and ET constitute two basic elements of the IPM. Economic injury level was defined as the lowest population density that will cause economic damage. The EIL is the most essential of the decision rules in IPM. In addition, the economic injury level provides an objective basis for decision making in pest management and the backbone for the management of pests in an agricultural system is the concept of EIL (Pedigo *et al.,* 1996). Ideally, an EIL is a scientifically determined ratio based on results of replicated research trials over a range of environments. In practice, economic injury levels tend to be less rigorously defined, but instead are nominal or empirical thresholds based on grower experience or generalized pest-crop response data from research trials.



Economic injury level and economic threshold of *H. armigera* on some crops was estimated by several researchers. In the case of *H. armigera* on soybean, these thresholds are poorly defined and a little information in this regard is available. However, economic thresholds; especially economic injury level; are dynamic and can be varied from year to year or even from field to field within a year depending on crop variety, market conditions, development stages of plant, available management options, crop value and management costs.

IPM Tactics:

Cultural management

Cultural control is the deliberate manipulation of the cropping or soil system environment to make it less favourable for pests or making it more favourable for their natural enemies. Many procedures such as tillage, host plant resistance, planting, irrigation, fertilizer applications, destruction of crop residues, use of trap crops, crop rotation, etc. can be employed to achieve cultural control. Early workers used cultural practices as the mainstay of their insect control efforts. Newsom (1975) pointed out that the rediscovery of the importance of cultural control tactics has provided highly effective components of pest management systems. Although some cultural practices have a noticeable potential in integrated management, use of some cultural controls is not universally beneficial. For example, providing nectar sources for beneficial insects may also provide nectar sources for pests.

It includes:

- Intercropping
- Ploughing and early planting effects on Helicoverpa populations
- Trap crops
- Push-pull strategy
- Host plant resistance
- Plant resistance to *H. armigera*


Biological control

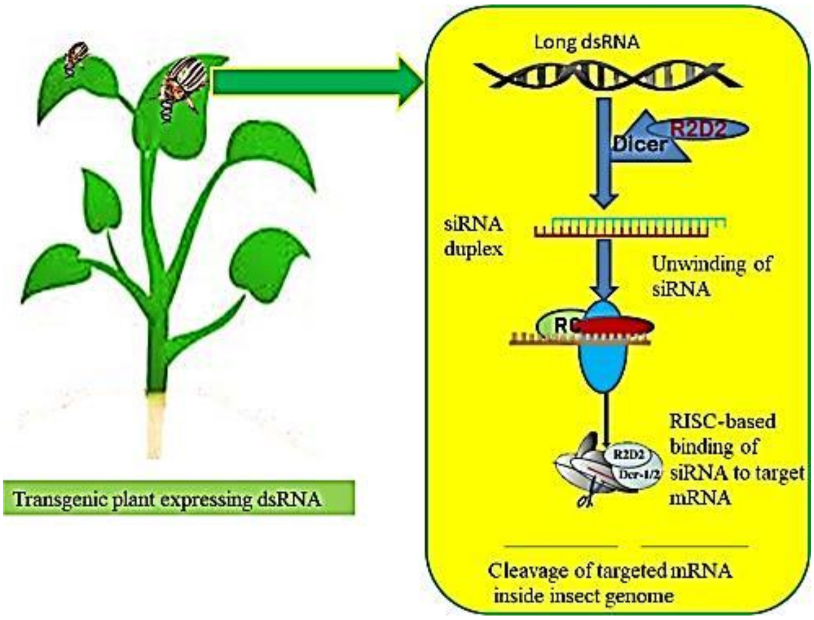
The value of biological control agents in integrated pest management is becoming more apparent as researches are conducted. Natural enemies clearly play an important role in integrated management of *Helicoverpa* spp., particularly in low value crops where they may remove the need for any chemical intervention. Likewise in high value crops (such as cotton and tomato) beneficial species provide considerable benefit but are unable to provide adequate control alone, especially in situations where migratory influxes of *Helicoverpa* result in significant infestations (Fitt, 1989). However, although parasitoids and predators cannot be relied upon for complete control of *H. armigera* in unsprayed area, knowledge about their role in cropping systems where *H. armigera* is an important pest is an essential component in the development of integrated management. Studies on the effects of parasitoids in biological control of *H. armigera* focused on monitoring parasitism of eggs and larvae. In Botswana, parasitism of larvae collected from different crops averaged up to 50% on sorghum, 28% on sunflower, 49% on cowpeas and 76% on cotton (Obopile and Mosinkie, 2007). In some cropping systems these predators have considerable impact on population of *Helicoverpa* spp. These biological control agents have been reported as major factors in mortalities of *H. armigera* in cotton agroecosystems in South Africa and in smallholder crops in Kenya. In South Africa the average daily predation rates of 37% and 30% of *H. armigera* eggs and larvae, respectively were found in absence of insecticides.

Chemical control

Chemical control is still the most reliable and economic way of protecting crops from pests. Besides, over reliance on chemical pesticides without regarding to complexities of the agro ecosystem is not sustainable and has resulted in many problems like environment pollution, secondary pest outbreak, pest resurgence, pest resistance to pesticides and hazardous to human health. Furthermore, over dependence on chemical pesticides has also resulted in increased plant protection, thus leading to high cost of production. Insecticide treatments, whether or not included in IPM programmes, are currently indispensable for the control of *H. armigera* in almost all cropping systems. Some of the synthetic insecticides currently used for controlling this pest are indoxacarb, methoxyfenozide, emamectin benzoate, novaluron, chlorfenapyr, imidacloprid, fluvalinate, endosulfan, spinosad, abamectin, deltamethrin, cypermethrin, lambda-cyhalothrin, carbaryl, methomyl, profenofos, thiodicarb and chlorpyrifos (Rafiee-Dastjerdi *et al.,* 2008). Because of indiscriminate use of these chemicals to minimize the damage caused by *H. armigera*, however, it has developed high levels of resistance to conventional insecticides such as synthetic pyrethroids, organophosphates and carbamates. After a pest species develops resistance to a particular pesticide, how do you control it? One method is to use a different pesticide, especially one in a different chemical class or family of pesticides that has a different mode of action against the pest. Of course, the ability to use other pesticides in order to avoid or delay the development of resistance in pest populations depends on the availability of an adequate supply of pesticides with differing modes of action. This method is perhaps not the best solution, but it allows a pest to be controlled until other management strategies can be developed and brought to bear against the pest (Rafiee-Dastjerdi *et al.,* 2008).

Biotechnology method in IPM

The most important application of biotechnology in IPM is the introduction of novel genes for resistance into crop cultivars through genetic engineering. HPR is a highly effective management option, but cultivated germplasm has only low to moderate resistance levels to some key pests. Furthermore, some sources of resistance have poor agronomic characteristics. On the other hand, development of cultivars with enhanced resistance will strengthen the control of *H. armigera* in different cropping systems. Therefore, we need to make a concerted effort to transfer pest resistance into genotypes with desirable agronomic and grain characteristics. Recent achievements of genetics and molecular biology have been widely implemented into breeding new crop cultivars and brought in many various traits absent from parent species and cultivars. Genetically engineered cottons expressing delta-endotoxin genes from *B. thuringiensis* offer great potential to dramatically reduce pesticide dependence for control of *Helicoverpa* spp. and consequently offer real opportunities as a component of sustainable and environmentally acceptable IPM systems (Shelton *et al.,* 2002). The major challenge to sustainable use of transgenic *Bt* crops is the risk that target pests may evolve resistance to the *B. thuringiensis* toxins. *Helicoverpa armigera* is a particular resistance risk having consistently developed resistance to synthetic pesticides in the past (Rafiee-Dastjerdi *et al.,* 2008). For this reason a pre-emptive resistance management strategy was implemented to accompany the commercial release of transgenic cultivars. The strategy, based on the use of structured refuges to maintain susceptible individuals in the population, seeks to take advantage of the polyphagy and local mobility of *H. armigera* to achieve resistance management by utilizing gene flow to counter selection in transgenic crops.



Conclusion:

In many regions of the world, *Helicoverpa armigera* poses a serious threat to soybean cropping systems, and it continues to be the focus of intensive management with synthetic pesticides. However, the widespread use of insecticides to control *H. armigera* populations raises environmental concerns as it has often resulted in the emergence of this pest's resistance as well as negative impacts on the environment and non-target creatures. It seems that in most areas the goal must be integrated management, particularly on crops like soybean where *H. armigera* is part of a diverse pest complex. The general trend towards reducing reliance on chemicals for control of insect pests in agriculture has rekindled interest in integrated pest management (IPM) programmes worldwide. As a result, we try to introduce the fundamentals of sustainable management of *H. armigera* in this chapter. In order to do this, we looked over the key conclusions of several scholars and, in some cases, presented our own evidence. However, our findings showed that greater focus should be placed on some fundamental details including monitoring initiatives, forecasting activities, and financial thresholds for effective management of *H. armigera*. Additionally, more research is required to assess the effectiveness of innovative management strategies for this nocturnal pest, including as selective insecticides, sublethal dosages, HPR, genetically modified soybean crops, and microbial diseases. However, the creation and application of resistant cultivars will be essential for the view of integrated management of *H. armigera* in soybean cropping systems.

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DIVERSITY OF PERILLA (*PERILLA FRUTESCENS* (L.) BRITT.) ACCESSIONS IN RAINFED GARHWAL HILLS OF UTTARAKHAND

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Abstract:

Perilla as an important commercial oilseed crophas high nutritional values. Wide variations are noted among the various germplasm accessions in the plants of perilla morphology and phonology that are still unknown. Therefore, to maximize the use of perilla germplasm for breeding program, it is necessary to study the morphological variation among the different germplasm accessions. The field study to study the morphological variation in 29 perilla germplasm was studied through eight quantitative characters. The quite high variation among the germplasm accessions of perilla were observed in plant growth, seed yield and yield contributing characters. Seed yield of the germplasm accessions ranged from 1.81 to 29.89 g plant^{-1}. The potential accessions IC615380, IC615375, IC615371, IC615383 and IC615374 have higher yields compared to the best check Jyantia.

Keywords: Perilla, Jyantia, Germplasm, Promising lines, Seed yield

Introduction:

Perilla (*Perilla frutescens* (L.) Britt.) is an important commercial oilseed crop of Asia. Besides as oilseed crop, it is also used as medicinal and leafy vegetable purpose, because of high nutritional properties. It belongs to the family *Lamiaceae* having about 7000 species (Dhyani *et al.,* 2019). It is worldwide known by different local names that vary from area to area that follows 'Zisu' or 'Shiso' in Japan (Meng *et al.,* 2009), 'Silam' in Nepal and 'Deulkkae' or 'Tilkae' in Korea (Bhandari *et al.,* 2011; Kang and Lee, 2011). While, in India the name varies from the states like 'Bhanjeer' or 'Bhanjeera' in Uttarakhand, 'Hanshi' or 'Thoiding' in Manipur and 'Chhawchhi' in Mizoram. It is mainly cultivated in Uttarakhand, Uttar Pradesh, Himachal Pradesh and Kashmir states for its flavouring essential oil. Perilla seeds are roasted with onion and tomato toform chutney (sauce) and also used in the curry material (Chauhan *et al.,* 2013). It contains the highest amount of α-linolenic acid which is one of the essential nutrients in diet (Choi, 2015). The herb has mint like odour and musky.

It is grown in mixed cropping; the crop requires moisture absorbent soil but not a very fertile soil (Dhyani *et al.,* 2019).

The useful part of the plant are its leaves and seeds (Nitta *et al.,* 2003; Pandey and Bhatt, 2008; Singh, 2018; Asif, 2011) as they are used as flavouring agent for various dishes. It also has ability to protect from many health issues such as anxiety, depression, tumor, cough, allergy, intoxication. Seeds of perilla contain 31-51% of drying oil similar to linseed oil. It is also rich in protein (23.12%), crude fibre (10.28%), saturated acids (6.7-7.6%), oleic acid (14-23%), linoleic acid (11-16%), linolenic acid (50-70%) and has highest amount of essential omega-3 fatty acids or α-linolenic acid with balanced omega-6 fatty acids (Singh *et al.,* 2015). The oil of perilla seed contains α-linolenic acid at least 2-fold higher than that in fish oil (Suttajit *et al.,* 2014).

However, morphological variation and relationship among different perilla accessions are still unknown (Luitel *et al.,* 2017). Therefore, to maximize the use of perilla germplasm for breeding program, it is necessary to study the morphological variation among the different accessions.

Materials and Methods:

The germplasm accessions trial consisting of a set of 29 genotypes was evaluated for eight quantitative traits with two checks *i.e.* Jayantia and Shillong Local during *kharif* 2017 in terraced fields at the Crop Improvement Block of College of Forestry, VCSG Uttarakhand University of Horticulture and Forestry, Ranichauri, Uttarakhand, India. The field is situated between altitudes of about 1600 to 2200 m ASL having silty clay loam soil in texture. The soil of the experimental field is largely acidic in nature. The crop season from June to Nov- 2017-18 experienced high rainfall with short spell of drought particularly during the end of the season.

The experiment was laid out in an augmented block design with 2 rows of each germplasm in spacing of 45 cm x 15 cm. The seeds of the germplasm accessions were sown on 15/07/2017 and harvested during 28/12/2017 to 06/01/2018 depending on their maturity.

The crop was raised using standard package and practices recommended for the region. Data on yield and other parameters were recorded using standard procedure. Data observed were analyzed by analysis of variance using statistical software to establish the significant variations.

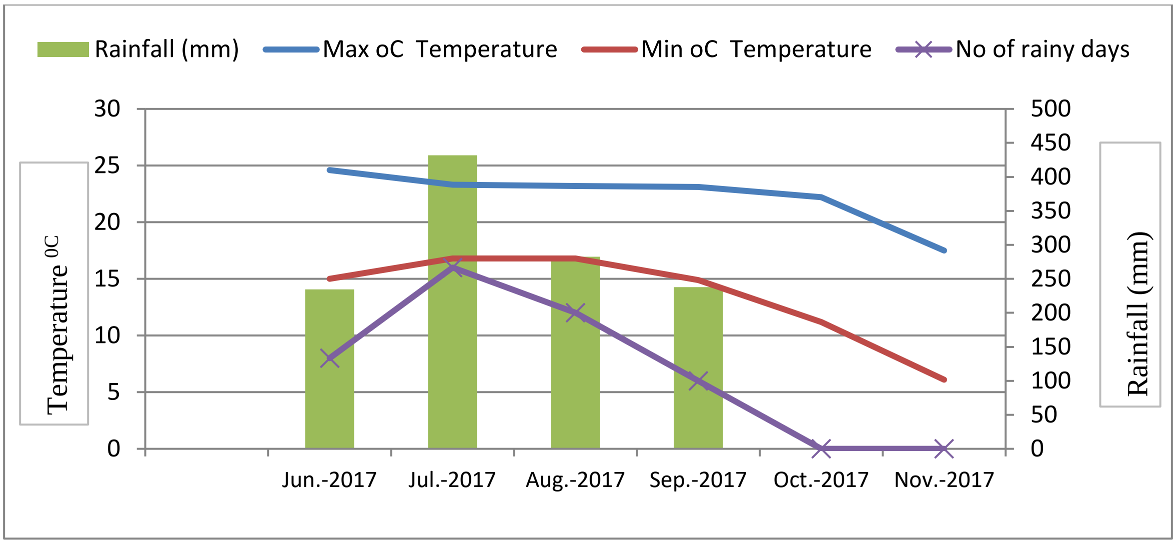

Fig. 1: Weather parameter during the crop season

Results:

The germplasm was recorded with wide variations for the yield contributing characters like days to 50% flowering, days to maturity, plant height, test weight, inflorescence length (cm), number of primary branches, number of leaves per plant and seed yield (g/plant). The days taken to 50% flowering and days to maturity ranged from 99 to 110 days and 164 to 175 days, respectively. IC615376 was early in 50% flowering (99 days) and maturity (164 days) followed by IC615384, IC615392, IC615370 and IC615374 which showed earliness than the best check Jyantia (Table 1).

Plant height of perilla germplasm varied from 38.4 to 119.4 cm. Accession IC615379 obtained maximum plant height (119.4 cm), IC615378 (111.4 cm) and IC615365 (110.0 cm) that were better than the best check Jyantia (107.6 cm). Minimum plant height was recorded in IC615385 (38.4 cm) (Table 2). The inflorescence length ranged from 3.6 to 11.6 cm. Among which, longest inflorescence was produced by accessions IC615382 (11.6 cm) followed by IC615375 (10.4 cm) which similar to the best check Jyantia (10.4 cm), while the shortest inflorescence length was obtained from IC615390 (3.6 cm) (Table 2).

Number of primary branches and leaves per plant varies from 1.4 to 7.6 and 4.5 to 22.2, respectively. Number of primary branches was found to be higher IC615373 (7.6) followed by IC615380 (6.7), IC615365 (6.6), IC615377 (6.2) and IC615375 (5.8) that were better than the best check Jyantia (5.4). However, number of leaves per plant was reported highest in IC615362 (22.2) followed by IC615364 (21.6), IC615365 (21.4), IC615371 (21.4) and IC615367 (20.2) that were better than the value of best check Jyantia (14.8) (Table 1).

Table 1: Morphological characters and yield of 29 perilla accessions

S. No.	Genotypes	Days to 50% flowering	Days to maturity	Plant height (cm)	Test weight (g)	Inflorescence length (cm)	No. of primary branches	No. of leaves/ plant	Seed yield (g/plant)
1	IC615362	105	170	57.2	0.19	6.4	5.0	22.2	14.07
2	IC615364	107	172	61.0	0.18	7.6	5.6	21.6	7.74
3	IC615365	109	174	110.0	0.20	7.8	6.6	21.4	1.81
4	IC615367	102	167	65.8	0.21	9.0	4.8	20.2	11.81
5	IC615368	105	170	76.6	0.24	9.0	5.2	17.6	5.33
6	IC615369	103	168	76.6	0.20	9.6	5.0	19.4	6.74
7	IC615370	101	166	76.4	0.17	8.4	4.0	13.0	8.00
8	IC615371	102	167	59.4	0.21	8.2	5.6	21.4	18.07
9	IC615372	104	169	59.8	0.19	7.8	5.2	16.2	15.04
10	IC615373	107	172	61.8	0.19	9.0	7.6	19.2	8.89
11	IC615375	103	168	80.8	0.23	10.4	5.8	13.0	20.78
12	IC615374	101	166	77.6	0.17	9.4	5.0	18.8	16.22
13	IC615376	99	164	74.8	0.19	5.8	5.0	10.8	14.18
14	IC615377	103	168	73.2	0.18	9.6	6.2	16.0	8.52
15	IC615378	105	170	111.4	0.21	8.6	5.4	16.4	8.18
16	IC615379	106	171	119.4	0.23	7.6	3.8	12.0	4.22
17	IC615380	108	173	87.0	0.18	8.2	6.7	10.4	29.89
18	IC615381	110	175	59.2	0.17	8.4	2.6	8.2	5.55
19	IC615382	103	168	100.6	0.21	11.6	3.6	10.6	4.78
20	IC615383	109	174	40.0	0.18	7.4	5.2	15.0	18.04
21	IC615384	100	165	69.6	0.23	9.2	2.8	6.6	7.92
22	IC615385	108	173	38.4	-	5.4	2.6	4.5	-
23	IC615386	105	170	79.0	0.24	6.2	3.2	13.0	11.85
24	IC615387	106	171	73.8	0.22	8.0	4.2	8.4	5.81
25	IC615389	108	173	79.4	-	8.4	3.2	11.8	-
26	IC615390	110	175	51.6	0.23	3.6	1.4	7.6	4.04
27	IC615391	102	167	59.6	0.22	5.8	3.6	10.2	14.52
28	IC615392	100	165	46.0	-	5.0	2.4	11.2	-
29	IC615393	106	171	46.6	0.24	5.0	2.4	11.2	5.81
	Jyantia	**101.7**	**166.7**	**107.6**	**0.21**	**10.4**	**5.4**	**14.8**	**12.45**

	Shillong Local	**104.7**	**169.7**	**83.5**	**0.20**	**8.8**	**5.4**	**13.6**	**7.99**
	Minimum	**99.0**	**164.0**	**38.4**	**0.17**	**3.6**	**1.4**	**4.5**	**1.81**
	Maximum	**110.0**	**175.0**	**119.4**	**0.24**	**11.6**	**7.6**	**22.2**	**29.89**
	Mean	**104.6**	**169.6**	**73.0**	**0.20**	**7.9**	**4.5**	**14.1**	**10.65**
	CV (%) Phen.	**2.97**	**1.83**	**28.45**	**11.10**	**22.79**	**32.52**	**34.54**	**58.15**

Table 2: Promising lines in perilla germplasm for various characters

S. No.	Characters	Range		Promising lines	Value of best check
		Min.	Max.		
1	Days to 50% flowering	99.0	110.0	IC615376 (99), IC615384 (100), IC615392 (100), IC615370 (101), IC615374 (101)	Jyantia (101.7)
2	Days to maturity	164.0	175.0	IC615376 (164), IC615384 (165), IC615392 (165), IC615370 (166), IC615374 (166)	Jyantia (166.7)
3	Plant height (cm)	38.4	119.4	IC615379 (119.4), IC615378 (111.4), IC615365 (110.0)	Jyantia (107.6)
4	100 grain (test) weight (g)	0.17	0.24	IC615386 (0.24), IC615368 (0.24), IC615393 (0.24), IC615379 (0.23), IC615375 (0.23)	Jyantia (0.21)
5	Inflorescence length (cm)	3.6	11.6	IC615382 (11.6), IC615375 (10.4)	Jyantia (10.4)
6	No. of primary branches	1.4	7.6	IC615373 (7.6), IC615380 (6.7), IC615365 (6.6), IC615377 (6.2), IC615375 (5.8)	Jyantia (5.4)
7	No. of leaves/ plant	4.5	22.2	IC615362 (22.2), IC615364 (21.6), IC615365 (21.4), IC615371 (21.4), IC615367 (20.2)	Jyantia (14.8)
8	Seed yield (g/plant)	1.81	29.89	IC615380 (29.89), IC615375 (20.78), IC615371 (18.07), IC615383 (18.04), IC615374 (16.22)	Jyantia (12.45)

The test weightvariation among the accessions ranged from 0.17 to 0.24 g. Germplasm IC615386, IC615368 and IC615393, each having 0.24 g, have maximum test weight followed by IC615379 (0.23 g) and IC615375 (0.23 g), which were better than the best check Jyantia (0.21 g). The seed yield per plantranges from 1.81 to 29.89 g. It was found maximum in accession IC615380 (29.89 g) followed by IC615375 (20.78 g), IC615371 (18.07 g), IC615383 (18.04 g) and IC615374 (16.22 g) compared to the best check Jyantia (12.45 g) (Table 1).

This research will facilitate in planning in situ management of perilla as potential oilseed crop of this region and in maintaining, selecting and utilizing the diverse germplasm in breeding programmes. Many researchers *viz*., Singh *et al.,* 2015, Luitel *et al.,* 2017, Oh *et al.,* 2021 also reported wide genetic variability in the perilla germplasm accessions.

Conclusion:

Wide variations were noted among the various perilla germplasm accessions. The potential accessions IC615380, IC615375, IC615371, IC615383 and IC615374 have higher yields compared to the best check Jyantia. IC615376, IC615384, IC615392, IC615370 and IC615374 accessions also reported for early in flowering and maturity. IC615379 germplasm accession obtained maximum plant height besides, is promising for test weight also. However, germplasm accession IC615382 gave longest inflorescence length. So, these many accessions can be used for hybridization purpose in crop improvement programme.

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USING ARIMA MODEL TO FORECAST PRODUCTION OF RABI SWEET POTATO IN ODISHA

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Abstract:

Sweet potato, which is frequently referred to as a small farmers crop, is a major vegetable crop of Odisha. In India, Odisha is producing the most sweet potatoes. In Odisha, sweet potatoes are grown during the Rabi (the dry post- monsoon) as well as Kharif (the rainy southwest monsoon). Sweet potato is grown as an irrigated crop during rabi season (October- December). A timely and accurate forecast of the area and production of such major vegetable crop is helpful for making agricultural policy decisions and giving nutrients to the population as the sweet potato occupies a key place among vegetable crops in Odisha. The objective of the present research is to predict the area, yield, and production of rabi sweet potato in Odisha by applying the ARIMA model.

The most widely used forecasting model, ARIMA, was applied in the study. ACF and PACF plots and secondary data on the area, yield, and production of rabi sweet potato were collected from 1970–1971 to 2019–20 to fit the models that were determined to be appropriate. The best fit model was chosen based on the importance of the estimated coefficients, model diagnostic tests, and model fit statistics. By refitting the model with data from the most recent 4 years, 3 years, 2 years and 1 year, as well as by making one step ahead forecasts for the years 2016–17 to 2019–20, and the best fit model was cross-validated.

The models with the best fits for the area, yield, and production of rabi sweet potatoes were found to be ARIMA (1,0,3) with constant model, ARIMA (0,1,1) with constant model, and ARIMA (0,1,1) without constant without constant. The forecast values show that the area, yield, and production of rabi sweet potatoes in Odisha will remain constant in future years, regardless of variation in the lower and upper class interval of the forecast values.

Keywords: ARIMA, cross validation, forecast, KPSS, MAPE, RMSE.

Introduction:

The major vegetable crop is the sweet potato in Odisha, which is occasionally referred to as a crop for small farmers. According to ASHS, 2007, sweet potatoes are the seventh-largest food crop in the world, after wheat, rice, maize, potato, barely, and cassava. Although almost all of states of India produce the crop, the eastern states Odisha, Kerala, West Bengal, and Uttar Pradesh produce the majority of the sweet potatoes in the country. Odisha is where most sweet potatoes are cultivated. sweet potatoes are produced on 130 thousand hectares in India, with a yield of 1470 thousand tonnes. Odisha is the highest producing state in terms of sweet potato production in India. Odisha has the largest area under sweet potato cultivation with production of 420.275 thousand tonnes from 404.10 thousand hectares of land. In India, sweet potatoes are grown throughout the Rabi (the dry post-monsoon season) and Kharif (the rainy southwest monsoon) seasons. Sweet potato is grown as an irrigated crop during rabi season (October- December). Rabi sweet potato is cultivated on about 19.81% of total area under sweet potato and 18.80% of total production of sweet potato.

A timely and accurate forecast of the area and production of such significant vegetable crops is valuable in terms of agricultural policy decisions and supplying nutrients to the population since sweet potatoes hold a significant position among the vegetable crops in Odisha. In this field of research, numerous researchers have contributed. Prabakaran *et al.* (2015) analysed the growth performance of sweet potato in India using ARIMA model. Dash *et al.* (2022) proposed a comparative study of spline regression and ARIMA model for forecasting the production of rabi food grains grown in Odisha. Vishwajit *et al.* (2018) studied about the modelling and forecasting of arhar in major arhar growing states in India using ARIMA and other models. The objective of the present research is to use the ARIMA model to predict the area, yield, and production of the rabi sweet potato in Odisha.

Material and Methods:

The secondary information regarding the area, yield, and production of rabi sweet potatoes in Odisha is collected from Five Decades of Odisha Agriculture Statistics, published by the Directorate of Agriculture and Food Production, Odisha, which covers the years 1970-1971-2019-20.

The auto-regressive integrated moving average (ARIMA) is a statistical method for predicting future trends. The ARIMA models are ARMA models with the order of differencing (which stationarise the data) included. A non-seasonal ARIMA model is referred to as a "ARIMA (p, d, q)" model, where the parameters p, d, and q stand for the number of autoregressive terms, nonseasonal differences needed to stationarize the data, and moving average terms, respectively.

The general forecasting equation used to express the ARIMA (p, d, q) model:

$$Y_t = \mu + \sum_{i=1}^{p} \phi_i Y_{t-i} + \sum_{j=1}^{q} \theta_j \varepsilon_{t-j} + \varepsilon_t$$

Where μ is the constant term, $\phi_1, \phi_2, \ldots \phi_p$ and $\theta_1, \theta_2, \ldots \theta_j$ are the parametric coefficients of the autoregressive term and moving average terms, respectively of the model.

Only stationary data are appropriate for the estimation of the ARMA model. To determine whether the data are stationary, the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test is used. The null hypothesis of KPSS test is H0: the data are stationary. The alternative hypothesis, H1: The data are non-stationary.

In order to make non-stationary data stationary, it is important to differenciate the data at an appropriate lag.

The most likely Moving Average (MA) and Auto Regression (AR) orders are identified using the Auto Correlation Function (ACF) and Partial Auto Correlation Function (PACF) plots after stationarizing the data. On the basis of the observed AR and MA orders, a number of ARIMA models are fitted, and their parameters are determined.

To determine the normality and independence of the residuals of the fitted models, the Shapiro-Wilk test and the Box-Pierce test, respectively, are used as model diagnostics tests.

The model fit statistics, such as the mean absolute percentage error (MAPE), root mean square error (RMSE), and Akaike's Information Criteria corrected (AICc), are used to compare the fitted models as follows:

Root mean square error (RMSE): $\sqrt{\frac{\sum_{t=1}^{n}(\hat{y}_t - y_t)^2}{n}}$

Mean absolute percentage error (MAPE): $\frac{100}{n}\sum_{t=1}^{n}\left|\frac{y_t - \hat{y}_t}{y_t}\right|$

Where $\hat{y}_t$ = forecasted value, y_t = actual value and n = number of times the summation iteration happens.

The model with the lowest RMSE and MAPE values among the fitted ARIMA models is selected as the most suited ARIMA model and utilised for forecasting following a successful cross validation. Using the forecast for one step ahead, the selected ARIMA model is cross-validated. To achieve this, a five-year prediction is used, covering 2016–17 to 2019–20.

The MAPE of the forecasted values for five years is calculated using the formula below:

MAPE = $\sum_{i=1}^{5} \frac{APE_i}{5}$

Where, APE_i is the absolute percentage error for the i^{th} period

$APE_i = \left(\frac{Y_i - \hat{Y}}{Y_i}\right)$

Where, Y_i is the observed value of i^{th} year in the left out period

$\hat{Y}$ is the forecast values of i^{th} year in the left out period

After a successful cross validation, the best fit ARIMA model is used to forecast the rabi sweet potato area, yield, and production in Odisha for the next years from 2020–2021 to 2024–2025.

Results and Discussion:

The KPSS test statistics of the data on area, yield, and production of rabi sweet potato in Odisha are shown in Table 1. The data of yield and production made stationary after first order difference while the data for area are stationary so no need to be differenced.

Table 1: Test of stationary of data on area, yield and production of rabi sweet potato in Odisha

Variable	Original series		First order differenced series	
	KPSS test statistics	P value	KPSS test statistics	P value
Area	0.266	0.1	---	---
Yield	1.118	0.01	0.059	0.1
Production	0.279	0.01	0.282	0.1

The next step involved using the ACF and PACF charts to determine the order of MA and AR variables like p and q.

The ordering of AR and MA terms were used to identify various fitted ARIMA models. The ACF and PACF plots showing raw data of area of the rabi sweet potato in Odisha are shown in Figs. 1. The ACF and PACF plots of First order difference data of yield and production of rabi sweet potato are shown in fig. 2 and fig 3.

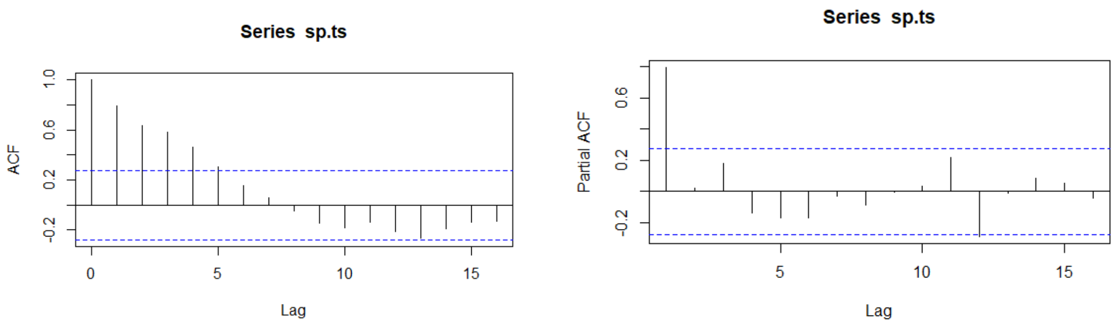

Fig. 1: ACF and PACF plot of area under rabi sweet potato in Odisha

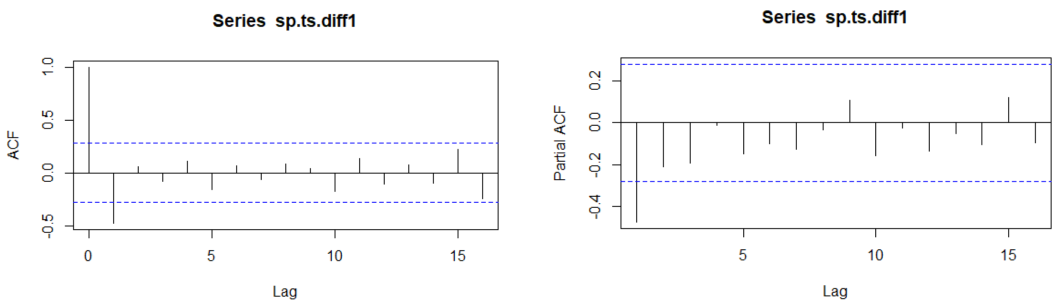

Fig. 2: ACF and PACF plot of first order difference of yield of rabi sweet potato in Odisha

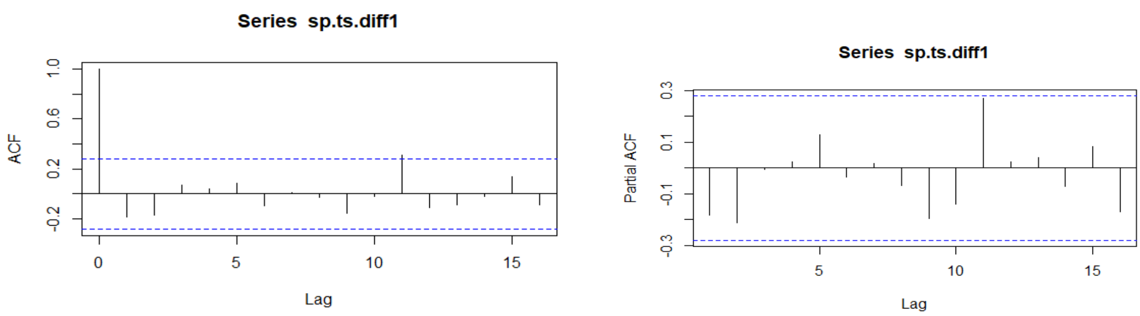

Fig. 3: ACF and PACF plot of first order difference of production of rabi sweet potato in Odisha

The fitted models to the data on area under rabi sweet potato and their estimated coefficients are shown in Table 2. The analysis of the table shows that the ARIMA (1,0,3) with constant and ARIMA (1,0,0) with constant models have significant estimates for the constants and first auto regressive parameter.

Table 2: Parameter estimates of the ARIMA (p, d, q) model fitted to area under rabi sweet potato

ARIMA (p, d, q)	Constant	Φ_1	Φ_2	Φ_3	θ_1	θ_2	θ_3
ARIMA (1,0,3) with constant	10.607** (2.829)	0.888** (0.075)			-0.142 (0.168)	-0.269* (0.114)	0.459* (0.203)
ARIMA (1,0,0) with constant	10.994** (2.444)	0.862** (0.074)					
ARIMA (1,0,1) with constant	10.661** (2.852)	0.894** (0.086)			-0.116 (0.228)		
ARIMA (2,0,0) with constant	10.866** (2.599)	0.826** (0.141)	0.044 (0.145)				
ARIMA (3,0,0) with constant	9.910* (3.429)	0.814** (0.137)	-0.170 (0.176)	0.266 (0.136)			

Figures inside the parenthesis indicate the standard error

** significant at 1% level *Significant at 5% level

Table 3: Model diagnostic test with model fit statistics of the ARIMA (p,d,q) model fitted to area under rabi sweet potato

ARIMA (p, d, q)	Model diagnostic test				Model fit statistics		
	Shapiro-Wilk test		Box- Pierce test				
	W	p-value	$\chi 2$	p-value	RMSE	MAPE	AIC
ARIMA (1,0,3) with constant	0.967	0.185	13.009	0.791	2.331	16.749	242.842
ARIMA (1,0,0) with constant	0.935	0.843	22.095	0.3354	2.542	17.205	243.076
ARIMA (1,0,1) with constant	0.935	0.847	22.246	0.3273	2.535	17.189	245.219
ARIMA (2,0,0) with constant	0.934	0.824	22.423	0.318	2.539	17.162	245.352
ARIMA (3,0,0) with constant	0.942	0.017	11.581	0.9297	2.440	16.495	244.128

The model diagnostics test results and model fit statistics for the fitted ARIMA models are shown in Table 3. The ARIMA (1,0,3) with constant model satisfies the tests for normality and independence of residuals and the model has low RMSE, MAPE, AIC values as compared to ARIMA (1,0,0) with constant. Therefore The ARIMA (1,0,3) with constant model is chosen as the one that fits the rabi sweet potato area the best.

Figure 4 further confirms the normality and independence of residuals.

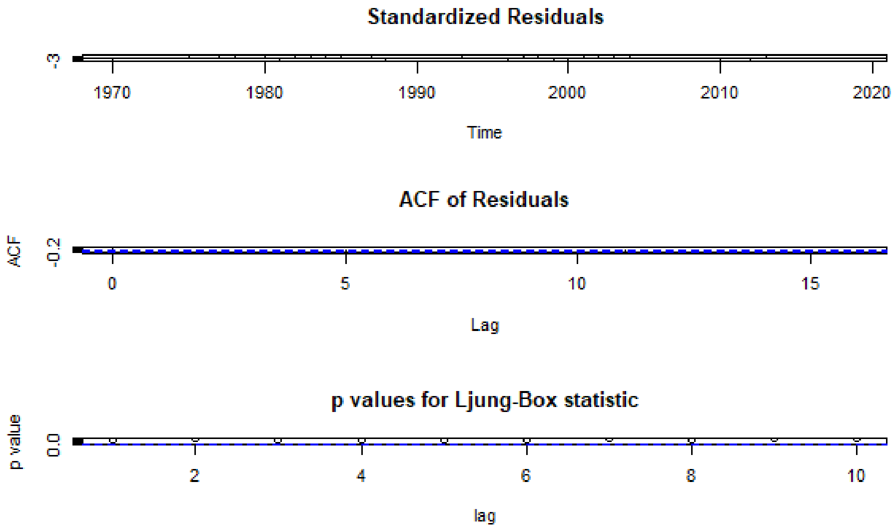

Fig. 4: Residual plot for fitting of ARIMA (1,0,3) with constant to rabi area of sweet potato

Table 4: Parameter estimates of the ARIMA(p,d,q) model fitted to yield of rabi sweet potato

ARIMA (p,d,q)	Constant	Φ1	Φ2	Φ3	θ1	θ2
ARIMA (0,1,1) with constant	69.877* (25.374)				-0.772** (0.146)	
ARIMA (1,1,0) with constant	58.777 (73.258)	-0.504** (0.127)				
ARIMA (2,1,0) with constant	61.729 (59.201)	-0.608** (0.142)	-0.219 (0.143)			
ARIMA (3,1,0) with constant	63.903 (48.169)	-0.656** (0.142)	-0.341* (0.162)	-0.211 (0.142)		
ARIMA (0,1,1) without constant					-0.601** (0.111)	

Figures inside the parenthesis indicate the standard error

** significant at 1% level *Significant at 5% level

Table 4 displays the fitted ARIMA models for yield and their estimated coefficients. The analysis of the table shows that all of the computed coefficients for the ARIMA (0,1,1) with constant and ARIMA (0,1,1) without constant models are significant.

The result of model diagnostics test and model fit statistics for the fitted ARIMA models for the yield of rabi sweet potato are shown in Table 5. In the case of ARIMA (0,1,1) with constant model has lower RMSE, MAPE, and AICc values than ARIMA (0,1,1) without constant model. So ARIMA (0,1,1) with constant model is chosen as the one that best fits the yield of the sweet potato in the rabi season.

Table 5: Model diagnostic test with model fit statistics of the ARIMA (p,d,q) model fitted to yield of rabi Sweet potato

ARIMA (p, d, q)	Model diagnostic test				Model fit statistics		
	Shapiro-Wilk test		Box- Pierce test				
	W	p-value	χ2	p-value	RMSE	MAPE	AIC
ARIMA (0,1,1) with constant	0.983	0.346	7.098	0.989	709.553	7.421	790.819
ARIMA (1,1,0) with constant	0.975	0.375	11.435	0.934	758.066	7.907	796.688
ARIMA (2,1,0) with constant	0.982	0.633	9.119	0.981	740.006	7.859	796.792
ARIMA (3,1,0) with constant	0.983	0.690	8.842	0.985	722.866	7.592	797.119
ARIMA (0,1,1) without constant	0.977	0.426	8.327	0.989	738.316	7.959	791.984

Figure 5 further validates the normality and independence of residuals.

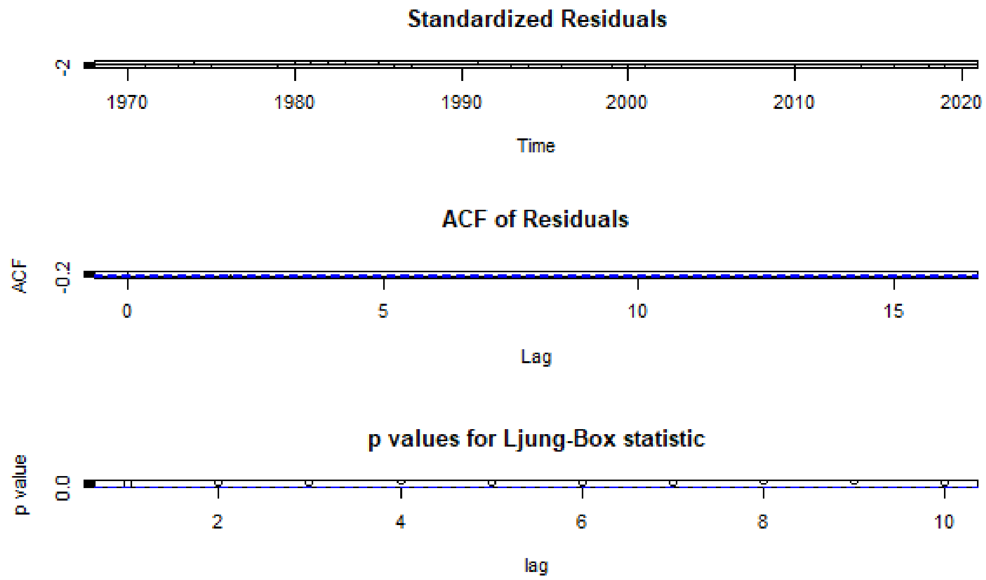

Fig. 5: Residual plot for fitting of ARIMA (0,1,1) without constant to yield of rabi sweet potato

Table 6 displays the fitted models and their estimated coefficients. The analysis of the table shows that the computed coefficients for the ARIMA (0,1,1) without constant model and ARIMA (0,1,1) with constant are significant, but the constant of ARIMA (0,1,1) with constant model is found to be not significant.

Table 6: Parameter estimates of the ARIMA(p,d,q) model fitted to production of rabi sweet potato

ARIMA(p,d,q)	Constant	Φ_1	θ_1	θ_2
ARIMA (0,1,1) without constant			-0.261 * (0.151)	
ARIMA (0,1,1) with constant	0.686 (2.668)		-0.263* (0.151)	
ARIMA (0,1,0) without constant				
ARIMA (0,1,0) with constant	0.704 (3.690)			
ARIMA (0,1,2) without constant			-0.199 (0.147)	0.127 (0.144)

Figures inside the parenthesis indicate the standard error

** significant at 1% level *Significant at 5% level

Table 7: Model diagnostic test with model fit statistics of the ARIMA (p,d,q) model fitted to production of rabi Sweet potato

ARIMA (p,d,q)	Model diagnostic test				Model fit statistics		
	Shapiro-Wilk test		Box- Pierce test				
	W	p-value	$\chi 2$	p-value	RMSE	MAPE	AIC
ARIMA (0,1,1) without constant	0.87428	0.675	11.248	0.8835	24.92053	18.42198	459.5153
ARIMA (0,1,1) with constant	0.87456	0.732	11.235	0.9399	24.90352	18.49303	461.7218
ARIMA (0,1,0) without constant	0.87428	0.689	11.248	0.9395	24.92053	18.42198	459.8302
ARIMA (0,1,0) with constant	0.85793	0.697	14.062	0.8273	25.57097	18.31059	461.9696
ARIMA (0,1,2) without constant	0.8829	0.743	9.1064	0.9816	24.71752	18.43918	461.0018

Table 7 displays the results of model diagnostic test and model fit statistics for the fitted ARIMA models for rabi sweet potato production. The ARIMA (0,1,1) without constant model satisfies the tests for residual independence and normality and has lower RMSE, MAPE and AICc value than other models. So, The ARIMA (0,1,1) without constant model is chosen as the one that best fits the production of the rabi sweet potato.

Figure 6 further confirms the normality and independence of residuals.

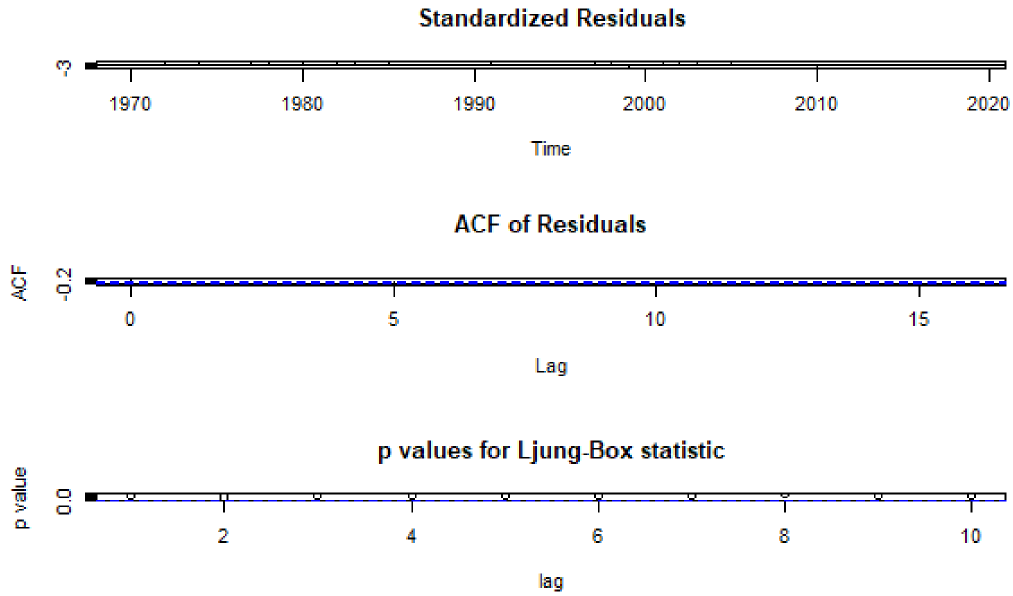

Fig. 6: Residual plot for fitting of ARIMA (0,1,1) without constant to production of rabi sweet potato

Table 8: Cross validation of area, yield and production of rabi sweet potato

Year	Area			Yield			Production		
	Actual	Predicted	APE	Actual	Predicted	APE	Actual	Predicted	APE
2016-17	6.17	7.268	17.796	8912	9615.646	7.895	54.99	59.488	8.179
2017-18	6.91	7.215	4.414	9443	9333.767	1.157	65.25	56.137	13.965
2018-19	6.64	7.317	10.196	9056	9377.268	3.547	60.13	62.884	4.580
2019-20	6.61	6.849	3.616	8956	9249.863	3.281	59.2	60.848	2.783
MAPE	9.005			3.970			7.377		

The results of cross validation for each variable related to the rabi sweet potato in Odisha shown in Table 8. The MAPE (mean APE) for the area under the rabi sweet potato is found to be 9.005 and the APE (absolute percentage error) is found to be in the range of 3 to 18. Similar to yield, where the APE ranges from 1 to 8 and the MAPE is 3.970, and production, where the APE ranges from 2 to 14 and the MAPE is 7.377. These findings demonstrate that cross validation of the chosen ARIMA models was successful.

The area, yield, and production of the rabi sweet potato in Odisha were predicted using respective selected best fit ARIMA models, which are shown in the table 9, for the years 2020–2021, 2021–2022, 2022–23, 2023–24, and 2024–25

Table 9: Forecast values of area, yield and production of rabi sweet potato for the year 2020-21 to 2024-25 using ARIMA model

Year	Area ('000ha)			Yield (kg/ha)			Production ('000tonnes)		
	Fore-casted	95 % confidence interval		Fore-casted	95 % confidence interval		Fore-casted	95 % confidence interval	
		Lower CI	Upper CI		Lower CI	Upper CI		Lower CI	Upper CI
2020-21	7.152	2.337	11.968	9522.305	8087.909	10956.70	59.630	9.779	109.481
2021-22	7.319	1.310	13.327	9592.183	8120.984	11063.38	59.630	-2.348	121.609
2022-23	7.582	1.282	13.882	9662.061	8154.958	11169.16	59.630	-12.464	131.725
2023-24	7.919	0.513	15.326	9731.939	8189.768	11274.11	59.630	-21.325	140.586
2024-25	8.219	0.044	16.394	9801.817	8225.357	11378.28	59.630	-29.308	148.569

Figures 7, 8 and 9 shows the actual, fitted and forecast values of area, yield and production of rabi sweet potato in Odisha. The fitted values of area under rabi sweet potato are closer to the actual values and the forecasted values are likely increasing from 2020-21 to 2024-25. The forecasted values are found to be constant in the case of yield and production of rabi sweet potatoes, with fitted values being closer to actual values.

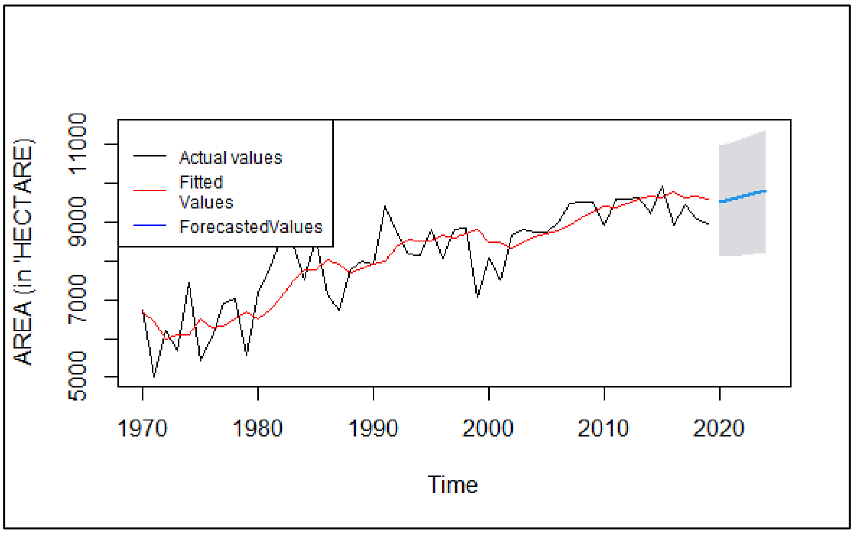

Fig. 7: Actual with fitted and forecasted values of area under rabi sweet potato from ARIMA (1,0,3) with constant model

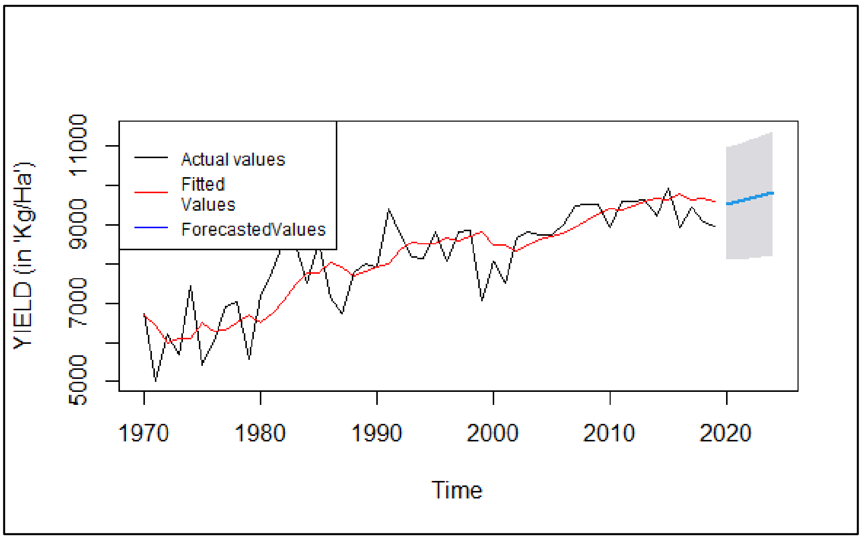

Fig. 8: Actual with fitted and forecasted values of yield of rabi sweet potato from ARIMA (0,1,1) with constant model

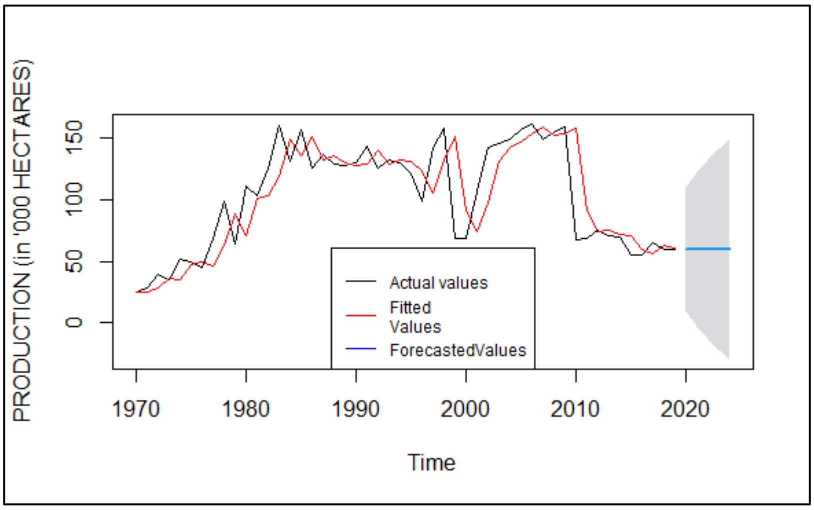

Fig. 9: Actual with fitted and forecasted values of production of rabi sweet potato from ARIMA (0,1,1) without constant model

Conclusion:

The best fits for the area, yield, and production of rabi sweet potatoes in Odisha were determined to be the models ARIMA (1,0,3) with constant model, ARIMA (0,1,1) with constant model, and ARIMA (0,1,1) without constant model. To forecast the area, yield, and production of rabi sweet potato in Odisha, some models have been used. In spite of deviations in the lower and upper class intervals of the forecast values, the area, yield, and subsequently production of rabi sweet potatoes in Odisha will remain consistent in the upcoming years.

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GROWTH AND INSTABILITY OF KHARIF GREEN GRAM PRODUCTION IN ODISHA

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Abstract:

The state of Odisha, which has an agrarian-based economy, primarily depends on agriculture for its population's livelihood. Around 9% of that total land is produced by pulse crops in Odisha. Green gram, also known as mung bean, is the most important pulse crop grown in the state of Odisha. It has 8.36 lakh ha area & produces 0.396 million tonnes annually at an average productivity of 434 kg per ha, accounting for roughly 40% of the state's total pulse area, which is very low by national and state standards. The current study aims to examine the growth rate and instability index of area, production and yield of green gram for kharif season in the districts of Odisha and as a whole, which would be useful in visualising the state's progress with regard to green gram cultivation and appropriate state policies. The study is based on secondary data for the years 1994-95 to 2017-18 that are gathered from various volumes of Odisha Agricultural Statistics, which is published by the Directorate of Agriculture and Food Production, Odisha. The compound growth rate and Cuddy Della instability index are used as measures of growth rate and instability of area, yield and production. Growth trends shows that for the study period of 1994-95 to 2017-18, the highest positive value is found in the district Puri on area and production but in aspect of yield, Jajpur district has highest negative growth rate. The district Bhadrak has the highest instability index value on area, production and yield, followed by Balasore on area and production, Puri & Jajpur in all aspects. The compound growth rate in area and yield of kharif green gram in Odisha is positive and significant whereas in case of production, Odisha is positive but insignificant. In most of the districts, the growth rate is positive and significant. The instability is highest in Odisha in production than area and yield. Thus, the higher instability in yield is due to the interaction effect of area and production. The instability in yield in the state was found to be 23.71 respectively during the overall period of the study.

Keywords: growth rate, instability, production, significant

Introduction:

Agriculture is the chief occupation of Odisha. As Odisha is an agrarian state where about 83 percent of the population lives in rural regions and 61.8 percent of the workforce is employed in agriculture and related industries. Agriculture is without a doubt the main source of employment in India, especially in the vast rural areas. In the kharif seasons, Odisha contributes 24.41% and 31.77%, respectively. When compared to the overall area and production of pulses in India, Odisha accounts for roughly 9% of that total land and produces 8% of it in pulse crops. The primary pulse crop farmed in the state of Odisha is green gram, referred to as mung bean. It has 8.36 lakh ha area and generates 0.396 million tonnes per year at an average productivity of 434 kg per ha, accounting for about 40% of the state's total pulse area, which is very low by national and state standards.

Agriculture growth and instability have remained the subject of intense debate in the agricultural economics literature in India. The need for greater agricultural growth or production is evident, but the rise in fluctuation viewed adversely for a number of reasons. It increases the risk related to agricultural production, affects farmer income, and influences their choices to adopt high-paying technologies and invest in farming. Production instability has an impact on consumers, price stability, and the ability of low-income households to get into the market. The government needs to give agricultural research greater funding in order to encourage agricultural growth in the state. Odisha has produced a lot, although not in the same proportion in each of its 30 districts.

The compound growth rate and instability of area, production and yield of green gram for kharif season in the districts of Odisha and the state as a whole are studied first. With the aid of this study, policymakers may better understand what will be needed in the future and develop strategies to meet those needs, such as choosing high-yielding cultivars, training farmers to adopt better cultural practises, providing enough inputs, and utilising the latest technologies. These pulse crops can also be imported and exported with planning. To assure farmers' income security, food availability, risk management, investment, and policy concerns in the agricultural sector, managing instability is essential.
Keeping in view the above perspectives the study has been made regarding area, production and yield of kharif green gram in all the 30 districts of Odisha for the period from 1994-95 to 2017-18.

Materials and Methods:

The study is based on secondary sources on area, production and yield of green gram crop for Kharif season in the districts of Odisha from 1994–1995 to 2017–2018. The data are gathered and compiled from several volumes of Odisha Agriculture Statistic, which is issued by the government of Odisha's Directorate of Agriculture and Food Production, Government of Odisha. The area, production and yield are expressed in '000 ha, in '000 MT & in kg/ha respectively.

Compound Growth Rate (CGR) analysis

The data on area, production and yield of green gram of kharif season in Odisha are worked out for entire period of analysis. For computing compound growth rate of area, production and yield of green gram in all districts, the exponential function of the following form are used as follows: $X_t = ab^t$

where, X_t = Area / Production / Yield of green gram in years

t = time element which takes the value 1,2,3….n

a = intercept; b = regression coefficient

The compound growth model is established in the following manner

$$\ln X_t = \ln a + t \ln b$$

$$X_t{}' = A' + B't$$

Let $\ln X_t = X_t{}'$; $\ln a = A'$; $\ln b = B'$

After solving the generalized equation, we get

$$B' = \frac{\sum_{t=1}^{n} t\, X_t^l - \sum_{t=1}^{n} \mathbf{t} . \sum_{t=1}^{n} X_t^l}{\sum_{t=1}^{n} t^2 - \left(\sum_{t=1}^{n} t\right)^2}$$

$$A' = \frac{\sum_{t=1}^{n} t\, X_t^l . B \sum_{t=1}^{n} \boldsymbol{t}}{n}$$

Given $\ln a = A'$; $a = e^A$; $\ln b = B$; $b = e^B$

Compound growth rate (CGR) =(b-1) × 100

Standard Error (SE) = ln b × (ln b / ln 10) (Dhakre and Sharma,2010)

Cuddy-Della Instability index

Cuddy-Della Instability Index is the broadly used procedure to analyse the instability of any given time series data and is universally acceptable. The indices were originally developed by John Cuddy and Della Valle for measuring the instability in time series data. This index is a better measure compared to coefficient of variation, as it is inherently adjusted for trend, which may be linear or non-linear. This measure included as a component of instability all cyclical fluctuations present in the time series data, whether regular or irregular, as well as any component which could be defined as 'white noise". It is a better indicator of agricultural production stability.

Cuddy-Della Instability Index is represented as (CDII) and given as,

CDII = CV × $\sqrt{1 - R^2}$ (Kumar *et.al.* 2018)

where,

CV = Coefficient of Variation = $\frac{\sigma}{\bar{Y}}$ × 100

σ = Standard deviation of Mean area / yield / production

$\bar{Y}$ = Mean of area / yield / production

R^2= Coefficient of determination from a time trend regression adjusted for its degree of freedom

Test of Significance of differences in sample variances of area/yield/production for two categories

Sample variance (s^2)of area / yield / production is given by: $s^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}$

Sample variance provide an estimate of population variance

<u>F-test is used to compare the two variances</u>

Null hypothesis; $H_0: \frac{\sigma_1^2}{\sigma_2^2} = 0$ (where σ_1^2 and σ_2^2 are two sample variances)

Alternate hypothesis; $H_1: \frac{\sigma_1^2}{\sigma_2^2} \neq 0$ (two tailed test)

Level of Significance; α = 0.05 (5%) or 0.01 (1%)

Test statistic F is given F = $\frac{s_1^2}{s_2^2}$ (if $s_1^2 > s_2^2$) Or F = $\frac{s_2^2}{s_1^2}$ (if $s_2^2 > s_1^2$)

s_1^2 is the sample variance of Group 1; s_2^2 is the sample variance of Group 2

Test of significance of difference in sample means of area/yield/production for two categories

Null hypothesis; $H_0: \frac{\mu_1}{\mu_2} = 0$ i.e. the two population means are identical

Alternate hypothesis; $H_1: \frac{\mu_1}{\mu_2} \neq 0$ (two tailed test)

Case 1: σ_1^2, σ_2^2 unknown, but assumed to be equal

Let the populations be homoscedastic (having equal variance), i.e. $\sigma_1^2 = \sigma_2^2 = \sigma^2$ (unknown)

Here we estimate σ^2 by a pooled estimator, $s_p^2 = \frac{(n_1-1)s_1^2 + (n_2-1)s_2^2}{n_1 + n_2 - 2}$

It is to be noted that both $s_1$and s_2 are unbiased estimator of σ, the common variance

Here the test statistic (known as Fisher's t-statistic)

$t = \frac{(\bar{x}_1 - \bar{x}_2) - (\mu_1 - \mu_2)}{s_p\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$ follows a t -distribution (Fisher's distribution) with d.f $n_1 + n_2 - 2$

Case 2 : σ_1^2, σ_2^2 unknown and unequal

If there is no reason to assume that the unknown variances, σ_1^2 and σ_2^2 of the two independent normal populations are equal, then we estimate σ_1^2 and σ_2^2 separately from the sample data and get the respective unbiased estimators as

$$s_1^2 = \frac{1}{n_1 - 1}\left\{\sum_{i-1}^{n_1} x_{1i}{}^2 - \frac{(\sum_{i=1}^{n_1} x_{1i})^2}{n_1}\right\};\ s_2^2 = \frac{1}{n_2 - 1}\left\{\sum_{i-1}^{n_1} x_{2i}{}^2 - \frac{(\sum_{i=1}^{n_2} x_{2i})^2}{n_2}\right\}$$

Then the test statistic,

$t = \frac{(\bar{x}_1 - \bar{x}_2) - (\mu_1 - \mu_2)}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$ follows a t -distribution approximately with d.f v given by

$$v = \frac{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)^2}{\frac{\left(\frac{s_1^2}{n_1}\right)^2}{n_1 - 1} + \frac{\left(\frac{s_2^2}{n_2}\right)^2}{n_2 - 1}} = \frac{(v_1 + v_2)^2}{\frac{(v_1)^2}{n_1 - 1} + \frac{(v_2)^2}{n_2 - 1}}$$

The approximation gives good results when n_1 and n_2 both are 5 or larger. This procedure is known as Welch's approximation method.

Results and Discussion:

The main focus of this paper is to examine how year to year fluctuations in crop output and what is the effect on the instability in the crop output. Accordingly, instability index and growth rate of area, production and yield of kharif green gram has been studied with 5% level of significance at district level in Odisha.

The compound growth rate in Odisha, the area and yield of kharif green gram have positive compound growth rates that are significant, which results in an insignificant compound growth rate of green gram production. Except for Cuttack, Khurda, and Sundargarh, all of the districts exhibit significantly positive compound growth rates of area under kharif green gramme, while Kandhamal, Koraput, Rayagada, Kalahandi, Jharsuguda, and Dhenkanal exhibit insignificantly negative growth rates. With the exception of Cuttack, Jharsuguda, Khurda, and Nayagarh, which show negative growth rates, the compound growth rate of production is generally positive and significant. Sundargarh is the only district with a negligibly negative compound growth rate. Except for some districts like Balasore, Bhadrak, Deogarh, Jajpur, Sundargarh, Puri, and Nayagarh, which exhibit significantly negative compound growth rates, the majority of districts exhibit positive and significant compound growth rates of yield. The only districts without a compound growth rate in terms of area, production, and yield are Jagatsinghpur and Kendrapada.

Table 1: Compound growth rate of area, production and yield of kharif green gram

Sl. No	Districts	Area	Production	Yield	Sl. No	Districts	Area	Production	Yield
1	Angul	1.62*	5.27*	3.59*	16	Kandhamal	-1.13	0.54	1.7*
2	Balasore	4.32	12.19*	-24.27*	17	Kendrapada	0	0	0
3	Balangir	2.77*	4.58*	1.77	18	Keonjhar	1.89	3.26*	1.35
4	Bargarh	3.44*	2.32	-1.08	19	Khurda	-3.4*	-2.54	0.9
5	Bhadrak	10.5*	14.02*	-18.05*	20	Koraput	-0.61	1.16	1.79*
6	Boudh	2.19*	4.83*	2.58*	21	Malkangiri	7.25*	10.48*	3.01*
7	Cuttack	-5.27*	-5.79	-0.55	22	Mayurbhanj	1.19	3.57*	2.35*
8	Deogarh	4.77*	2.6*	-2.08*	23	Nabrangpur	0.21	1.18	0.98
9	Dhenkanal	-0.61	2.44	3.07*	24	Nayagarh	0.14	-1.002	-7.74*
10	Gajapati	0.07	0.41	-5.79	25	Nuapada	3.77*	9.27*	5.3*
11	Ganjam	0.59	1.67*	1.08*	26	Puri	15.99*	16.85*	-23.71*
12	Jagatsinghpur	0	0	0	27	Rayagada	-0.98	0.39	1.38
13	Jajpur	4.16*	8.79*	-26.06*	28	Sambalpur	4.06*	4.83*	0.74
14	Jharsuguda	-1.19	-1.35	-0.16	29	Sonepur	2.37*	3.2*	0.83
15	Kalahandi	-1.11	0.11	1.24	30	Sundargarh	-3.88*	-6.08*	-2.29*
	Odisha	1.8*	0.93	2.75*					

Table 2: Instability index of area, production and yield of kharif green gram

Sl. no.	Districts	Area	Production	Yield	Sl. No.	Districts	Area	Production	Yield
1	Angul	12.62*	43.65*	39.02*	16	Kandhamal	23.79*	42.69*	26.13*
2	Balasore	227.8*	225.46*	45.83*	17	Kendrapada	0	0	0
3	Balangir	8.26	35.16*	31.89*	18	Keonjhar	33.3*	37.25*	22.51*
4	Bargarh	9.62	25.5*	28.79*	19	Khurda	58.66*	66.42*	20.92*
5	Bhadrak	269.22*	239.71*	175.76*	20	Koraput	52.82*	82.97*	25.62*
6	Boudh	18.36*	29.28*	28.99*	21	Malkangiri	44.11*	57.2*	33.32*
7	Cuttack	71.19*	84.3*	20.59*	22	Mayurbhanj	26.17*	38.2*	23.43*
8	Deogarh	17.68*	22.45*	22.96*	23	Nabrangpur	58.72*	72.85*	33.19*
9	Dhenkanal	24.61*	55.47*	37.16*	24	Nayagarh	42.6*	67.32*	39.45*
10	Gajapati	57.24*	54.51*	23.61*	25	Nuapada	7.8	45.03*	42.75*
11	Ganjam	14.87*	23.27*	13.13*	26	Puri	170.18*	194.83*	123.97*
12	Jagatsinghpur	0	0	0	27	Rayagada	59.02*	92.21*	36.46*
13	Jajpur	165.91*	128.6*	121.24*	28	Sambalpur	18.32*	41.54*	29.33*
14	Jharsuguda	38.79*	40.15*	12.1*	29	Sonepur	24.09*	30.06*	15.48*
15	Kalahandi	38.2*	58.9*	26.47*	30	Sundargarh	15.52*	27.69*	21.68*
	Odisha	11.58	18.24*	23.71*					

The instability index of Odisha is highest in case of yield of kharif green gram than in area and production. Thus the higher instability in yield is due to the interaction effect of area and production. Most of the districts have instability index goes above 50% but some are less than 20% in terms of area. The districts like Jajpur, Bhadrak, and Puri have high rate of instability in area, yield and production whereas in case of Balasore district, it shows highest instability index which goes above 80%. in respect of area and production only. The districts liker Jagatsinghpur and Kendrapada doesnot show any instability index regarding area, yield and production of kharif green gram. The instability index are lowest which goes below 10% in term of area in districts Balangir, Bargarh, Nuapada.

Figure 1 shows the graphical presentation of compound growth rate of area, production and yield of kharif green gram for different districts of Odisha. The study of the figure reveals that compound growth rate is found to be positive for most of the districts in terms of area, yield and production and negative growth rate in some of the districts like Balasore, Bargarh, Bhadrak, Cuttack, Dhenkanal, Deogarh, Gajapati, Jajpur, Nayagarh, Puri, Sundargarh in terms of yield, districts like Cuttack, Jharsuguda, Kalahandi, Kandhamal, Khurda, Rayagada, Sundergarh in terms of area. The remaining districts have seen positive growth in terms of production, with the exception of Khurda, Nayagarh, Cuttack, Jharsuguda, and Sundaragarh. In terms of area and production, the district of Puri has the highest growth rate.

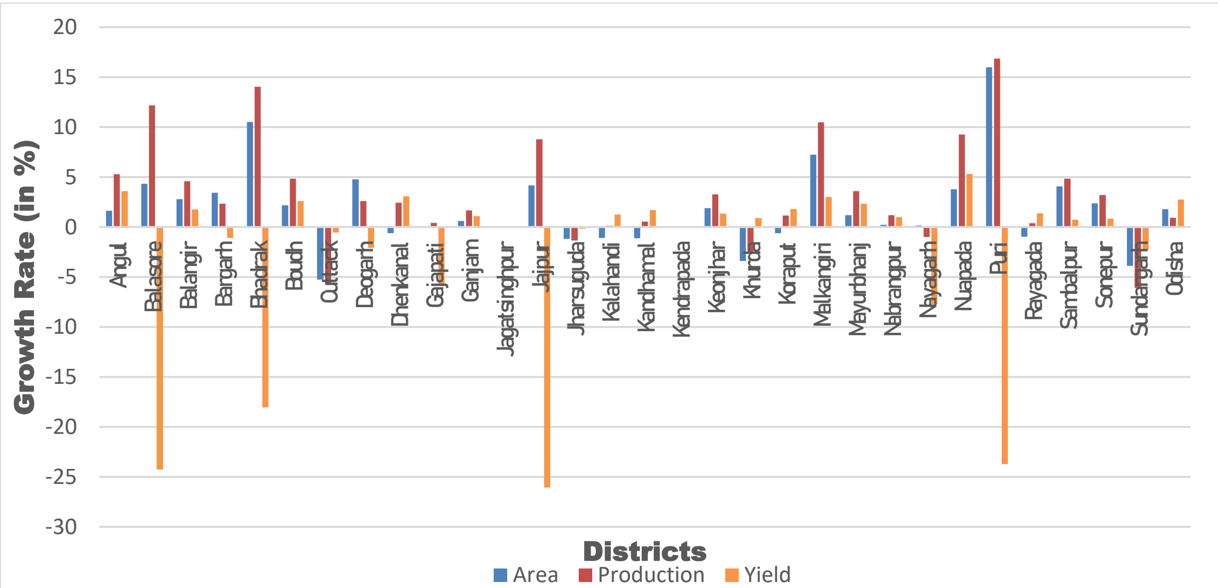

Fig. 1: Multiple Bar Diagram showing the growth rate (in %) of area, yield, production of kharif green gram

Figure 2 shows the graphical representation of instability index of area, yield and production of kharif green gram of different districts of Odisha. The study of the figure reveals that in some districts the instability goes above 40% even some are less than 10% instability. Some districts like Bhadrak, Balasore, Jajpur, Puri has highest instability which goes above 150%.

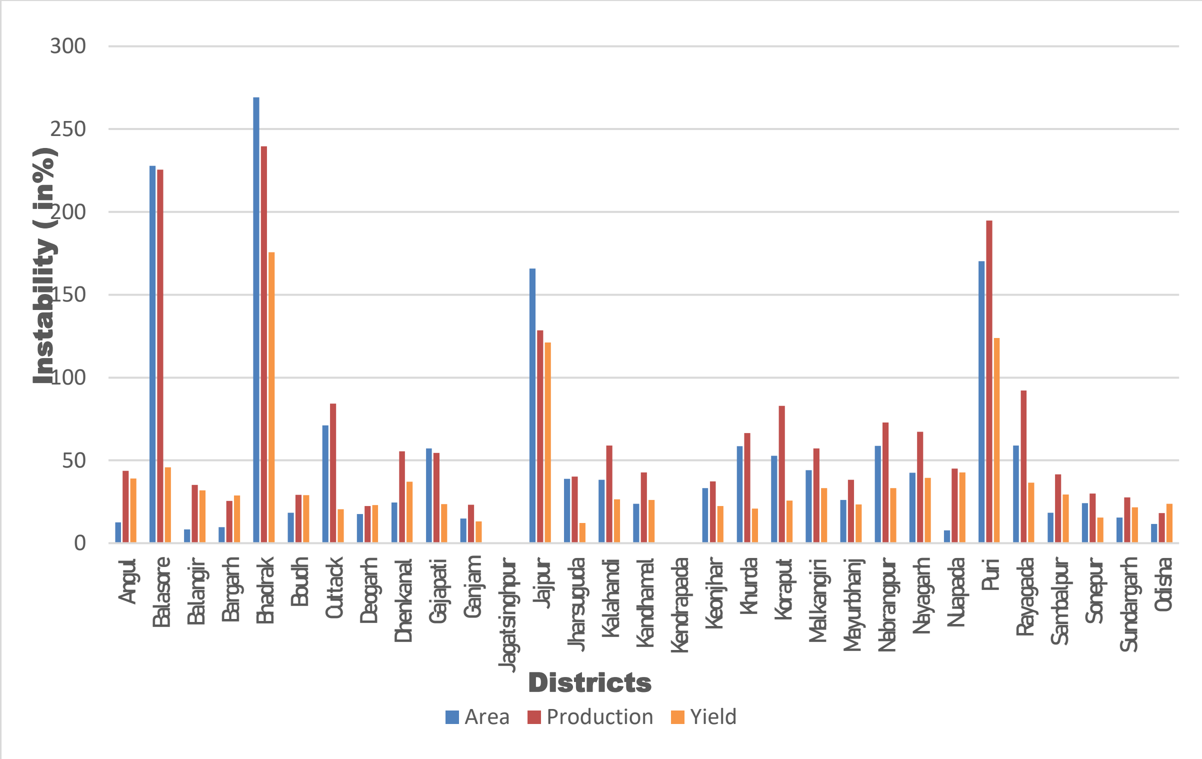

Fig. 2: Multiple Bar Diagram showing the instability index (in %) of area, yield, production of kharif green gram

Table 3 shows value of growth rate and instability of area, production and yield of kharif green gram crop after testing the significance difference between two categories that are classified according to the Odisha growth rate and instability data.

Table 3: Value of growth rate and instability of area, production and yield of kharif green gram crop

Growth Rate	**Area**	**Production**	**Yield**	**Instability**	**Yield**
Variance (A)	156.79	17.41	290.48	**Variance (A)**	13263.58
Variance (B)	51.96	16.58	21679.98	**Variance (B)**	28212.66
f-value	3.176	1.049	74.635	**f-value**	2.127
p-value	0.021	0.487	1.307	**p-value**	0.079
Mean(A)	9.51	3.17	337.03	**Mean(A)**	317.55
Mean(B)	4.47	1.85	329.21	**Mean(B)**	349.31
ǀtǀ-value	1.296	0.841	0.259	**ǀtǀ-value**	0.616
p-value	0.211	0.408	0.797	**p-value**	0.543

Table 4 shows grouping of districts of Odisha on basis of growth rate and instability index of area, production and yield.

Table 4: Grouping of districts of Odisha on basis of growth rate and instability index of area, production and yield

Grouping	Area	Production	Yield
1A	Balasore, Cuttack, Khurda, Sundargarh	Sundargarh	Balasore, Bhadrak, Deogarh, Jajpur, Nayagarh, Sundargarh, Puri
1B	-NA-	-NA-	-NA-
2A	Angul, Deogarh, Jajpur, Malkangiri, Sonepur, Sambalpur, Puri	Angul, Balasore Balangir, Bhadrak, Boudh, Deogarh, Ganjam, Jajpur, Keonjhar Sonepur, Sambalpur, Puri, Nuapada, Mayurbhanj, Malkangiri, Keonjhar	Angul, Boudh, Dhenkanal, Ganjam, Kandhamal, Koraput, Malkangiri, Mayurbhanj, Nuapada
2B	Balangir, Bargarh, Nuapada	-NA-	-NA-
3A	Balasore, Dhenkanal, Gajapati, Gajapati, Jharsuguda, Kalahandi, Kandhamal, Keonjhar, Koraput, Mayurbhanj, Nabreangpur, Nayagarh, Rayagada	Bargarh, Cuttack, Dhenkanal, Gajapati, Jharsugudam Kalahandi, Kandhamal, Khurda, Rayagada, Nayagarh , Nabrangpur, Koraput, Khurda	Balangir, Bargarh, Jharsuguda, Kalahandi, Keonjhar, Khurda, Nabrangpur, Rayagada, Sambalpur, Sonepur, Cuttack, Gajapati,
3B	Bhadrak, Boudh, Jagatsinghpur Kendrapada	Jagatsinghpur Kendrapada	Jagatsinghpur, Kendrapada

Note: 1- Negative, 2- Positive, 3-Non-Significant; A- Significant, 2- Non -Significant

Conclusion:

The study highlighted the fact that the growth of area, production and productivity for green gram in Odisha mostly registered as positive and statistically significant at 5% level of significance. Over the years the compound growth rate of all three aspects continues to be positive in most of the districts but has been declining in some districts. The instability index for kharif season of green gram shows positive and high in nature usually in production aspect the instability goes above 40% in most districts while Odisha has lowest instability index compared to all districts. The study of growth rate in kharif season gives us a idea regarding the change in performance of green gram crop in Odisha during different time periods. As, there are several fluctuations in the growth pattern of area, production and productivity of green gram, the policies need to be focused to increase the yields of the crop. Scientific methods of cultivation of crop and sustainable agriculture need to be carried out to increase the productivity.

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GROWTH AND INSTABILITY OF RABI RICE PRODUCTION IN ODISHA

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Abstract:

In Odisha, sustained agricultural growth rates have been a concern. The current study's objectives are to determine the district-level growth rates of area, production, and yield of Rabi rice as well as the level of instability in those districts of Odisha because rice is the primary crop cultivated in the region. The study is based on secondary sources of information on the production, yield, and area of rabi rice in the districts of Odisha from 1994–1995 to 2017–2018. The information was taken from several publications of Odisha Agriculture Statistics by the government of Odisha's Directorate of Agriculture and Food Production. The exponential model was used to calculate the growth rates for area, production, and yield. Cuddy Della Valle's instability index was used to measure the instability in the area, output, and yield of the districts in Odisha. Malkangiri, Kalahandi and Nuapada Districts had the greatest compound growth rate when compared to the entire region. In the district of Kandhamal, the lowest growth rate was recorded. In Kalahandi, Malkangiri, Nuapada, Koraput and Subarnapur the compound growth rate for production is noteworthy and highest. In terms of output and yield, the majority of districts are displaying positive growth rates.

Keywords: growth rate, instability, production, significant

Introduction:

Rice production in the Rabi season is a crucial aspect of agriculture in Odisha. While rice is traditionally a Kharif crop in the state, some regions with favorable climatic conditions also cultivate it during the Rabi season. This practice helps diversify crop cycles and enhance overall agricultural productivity. During the Rabi season, which spans from November to April, farmers in select areas of Odisha cultivate varieties of rice that are well-suited to the winter climate. This additional rice production contributes to food security and income generation for many households in the state. Despite the challenges posed by varying weather patterns and the need for appropriate irrigation, farmers in Odisha employ innovative techniques and agricultural practices to successfully grow rice in the

Rabi season, contributing to the state's agricultural diversity and overall food production. Odisha have total area of rabi rice during is 2.50 lakh hectares.

The study of growth and variability in area, production and yield of rice is very important for effective planning and strategy formulation. Various researchers have been contributing in this area of research. Jambhulkar *et.al* (2020) studied the growth rate and instability analysis of area, production and yield of Rice in Odisha state of India. Dey *et.al* (2020) worked on temporal growth and instability analysis of area, production and yield among the top three rice producer states i.e., West Bengal, Uttar Pradesh and Punjab. Sunandini *et.al* (2020) worked on analysis of trends, Growth and instability in rice production in Andhra Pradesh using Compound growth rate and Cuddy Della Instability index. Despite tremendous improvements in agricultural productivity, not all of Odisha's districts have seen the same level of development. The analysis of patterns in rice production, area, and productivity in the state as well as in significant districts becomes important in this context. The area, production, and yield of rice were observed to be unstable for a number of reasons. Although there is a clear need for the agriculture sector to expand, Odisha's agricultural growth is more unpredictable because of the rising production instability. So, in order to analyse the factors, a study was conducted with the goals of examining the growth rate in the area, production, and productivity of the Odisha rice crop as well as the long-term stability of those rates.

Material and Methods:

The study is based on secondary source of data on area, yield and production of rice crop for rabi rice in the districts of Odisha from the period 1994-95 to 2017-18. The data are obtained from various volumes of Odisha Agriculture Statistics published by Directorate of Agriculture and food production, Government of Odisha.

Growth rate analysis

In the present study, compound growth rate of area, production and yield for rice for each period were estimated to study the growth in area, production and yield of rice. The district wise compound growth rates were estimated with the help of following exponential model

Y_t=ab^t

lnY_t = ln a +ln b

Where Y is the time series data on rice production, area, and yield by district t is the time term, and an is the constant coefficient. For a specific absolute change in the value of the explanatory variable t, the slope coefficient b calculates the relative change in Y. One can obtain the percentage change or growth rate in Y for an absolute change in the time variable t by multiplying the relative change in Y by 100.

The immediate rate of growth is measured by the slope coefficient. following formula can be used to compute the compound growth rate r: Compound growth rate (C.G.R) = (b-1) × 100

Instability analysis

The most widely used and widely accepted metric of instability for time series data is the Cuddy-Della Instability Index. John Cuddy and Della created the indices in the beginning to evaluate the level of instability in time series data. This index is a more accurate measurement than the coefficient of variation since it is automatically corrected for trend, which is frequently seen in time series data. This metric comprised any component that may be referred to as "white noise" as well as all cyclical fluctuations contained in the time series data, whether regular or irregular.

Cuddy – Della Instability (CDII) is given as,

$$\text{CDII} = \text{CV} \times \sqrt{1 - R^2} \qquad \text{(Kumar } et\ al.\text{, 2018)}$$

Where,

CV = Coefficient of variation = $\frac{\sigma}{Y}100$

σ= Standard Deviation of Mean Area/ Yield/ Production;

$\bar{Y}$ – Mean Area / Yield/ Production

R^2-Coefficient of determination from a time trend regression adjusted for its degree of freedom

Test of significance of difference in sample variances of area/yield/production for two sub-periods

Sample variance (s^2) of area/yield/production is given by:

$$s^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}$$

Sample variance provide an estimate of population variance

F-test is used to compare the two variances

The test procedure is as follows:

Null hypothesis; H_0: $\frac{\sigma_1^2}{\sigma_2^2}$ = 1 (where σ_1^2 and σ_2^2 are two population variances)

Alternative hypothesis; H_1: $\frac{\sigma_1^2}{\sigma_2^2} \neq 1$ (two tailed test)

Lev Test statistic F is given by

$F = \frac{s_1^2}{s_2^2}$(If $s_1^2 > s_2^2$) or $F = \frac{s_2^2}{s_1^2}$ (If $s_2^2 > s_1^2$)

s_1^2 is the sample variance of sub-periodI

s_2^2 is the sample variance of sub-periodII

$$s_1^2 = \frac{1}{n_1 - 1}\left\{\sum_{i=1}^{n_1} x_{1i}^2 - \frac{\left(\sum_{i=1}^{n_1} x_{1i}\right)^2}{n_1}\right\};\ s_2^2 = \frac{1}{n_2 - 1}\left\{\sum_{i=1}^{n_2} x_{2i}^2 - \frac{\left(\sum_{i=1}^{n_2} x_{2i}\right)^2}{n_2}\right\}$$

level of significance, α : 0.05 (5%)

Results and Discussion:

Table 1 shows the districts wise growth rate of area, production and yield of rabi rice in Odisha. It is found from the table that compound growth rate for area of rabi rice in all districts of Odisha is negative and significant. Some districts which show positively significant like Balesore, Bargarh, Kalahandi, Koraput, Malkangiri, Nuapada and Subarnapur. Compound growth rate for production is found to be positive for nearly 46 per cent of the districts, whereas the remaining districts show insignificant growth rate. The compound growth rate for yield is positive for most of the districts except Angul, Bhadrak, Deogarh, Kandhamal, Kendrapara, Mayurbhanj, Nabarangpur, and Nayagarh which show insignificant growth rate.

Table 2 shows the districts wise instability index of area, production and yield of rabi rice in Odisha. The study of the table shows that the instability index for area of rabi rice in all districts of Odisha is significant except Bargarh and Subarnapur which have insignificant Instability Index, which reveals that for the state, area is more unstable. All districts showing significant instability index in production except Subarnapur. Likewise maximum districts showing significant instability index in yield except Bargarh, Jajpur, Koraput and Sambalpur.

Table 1: District wise Growth rate of Area, Production and Yield of Rabi rice in Odisha

Si No	Ditricts	Area	Production	Yield	Si No	Districts	Area	Production	Yield
1	Angul	-11.42*	-10.44*	1.1	16	Kandhamal	0.08	1.99	-3.15
2	Balasore	1.39*	4.23*	2.8*	17	Kendrapara	-13.8*	-13.77*	-4.93
3	Bargarh	0.98*	3.3*	2.3*	18	Keonjhar	-2.77*	-0.6	2.23*
4	Bhadrak	-8.45*	-7.68*	0.84	19	Khurda	-11.57*	-9.7*	2.11*
5	Bolangir	1.82	5.65*	3.76*	20	Koraput	3.9*	6.96*	2.94*
6	Boudh	1.89	5.01*	3.06*	21	Malkangiri	12.09*	14.77*	9.38*
7	Cuttack	-10.21*	-8.64*	1.75*	22	Mayurbhanj	-3.96*	-2.89*	-3.91
8	Deogarh	-10.23*	-9.91	-5.76	23	Nabarangpur	0.52	1.93	1.39
9	Dhenkanal	-12.23*	-10.01*	2.53*	24	Nayagarh	-8.7*	-7.87*	-5.83
10	Gajapati	0.1	2.41*	2.31*	25	Nuapada	7.38*	12.29*	4.57*
11	Ganjam	-7.83*	-5.44	2.59*	26	Puri	-2.07	0.43	2.55*
12	Jagatsinghpur	-11.27*	-9.61*	1.87*	27	Rayagada	1.41	4.52*	3.07*
13	Jajpur	-8.88*	-7.75*	1.24*	28	Sambalpur	0.29	2.75	2.45*
14	Jharsuguda	-2.51	-1.22	1.32*	29	Subarnapur	2.31*	5.99*	3.6*
15	Kalahandi	11.15*	16.02*	4.38*	30	Sundargarh	-9.21*	-7.05*	2.37*
	Odisha	-0.04*	2.57*	2.62*					

*significance@5%

Table 2: District wise Instability index of Area, Production and Yield of Rabi rice

Si No	Districts	Area	Production	Yield	Si No	Districts	Area	Production	Yield
1	Angul	45.85*	55.22*	17.79*	16	Kandhamal	40.87*	41.07*	22.39*
2	Balasore	19.84*	24.77*	12.64*	17	Kendrapara	55.62*	60.99*	14.91*
3	Bargarh	9.7	16.67*	11.14	18	Keonjhar	35.25*	36.62*	13.8*
4	Bhadrak	50.3*	58.76*	18.62*	19	Khurda	57.2*	63.9*	12.74*
5	Bolangir	48.03*	47.91*	16.15*	20	Koraput	28.17*	34.97*	10.12
6	Boudh	49.57*	57.45*	21.8*	21	Malkangiri	122.93*	120.97*	32.5*
7	Cuttack	44.97*	53.56*	13.03*	22	Mayurbhanj	33.92*	34.44*	17.14*
8	Deogarh	91.09*	119.54*	40.04*	23	Nabarangpur	59.67*	68.14*	25.3*
9	Dhenkanal	49.07*	54.45*	15.13*	24	Nayagarh	114.64*	109.74*	22.15*
10	Gajapati	34.07*	58.34*	28.38*	25	Nuapada	49.85*	62.69*	25*
11	Ganjam	78.4*	82.48*	20.14*	26	Puri	38.82*	41.03*	15.65*
12	Jagatsinghpur	62.01*	76.67*	15.6*	27	Rayagada	44.17*	55.4*	14.3*
13	Jajpur	50.3*	56.18*	9.43	28	Sambalpur	35.48*	42*	8.08
14	Jharsuguda	64.58*	69.72*	20.08*	29	Subarnapur	11.1	18.75*	12.3*
15	Kalahandi	48.32*	46.72*	16.7*	30	Sundargarh	51.21*	57.29*	14.26*
	Odisha	17.48*	18.48*	9.07*					

*significance@5%

Figure1 shows the graphical presentation of compound growth rate of area, production and yield of rabi rice for different districts of Odisha.

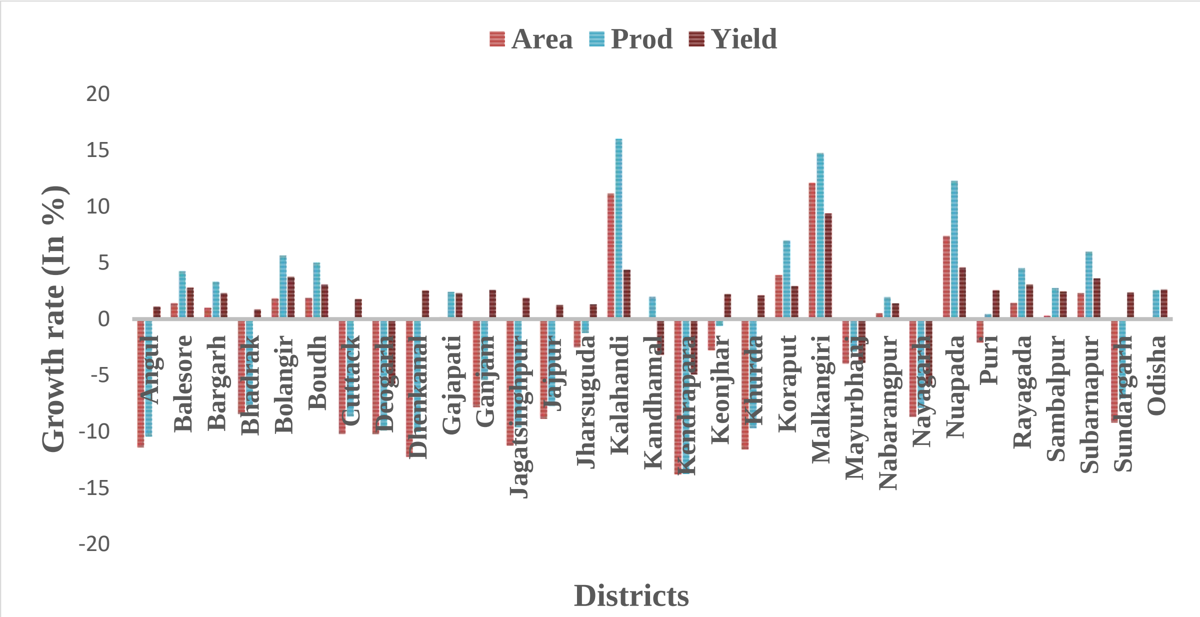

Fig. 1: Multiple bar diagram showing the compound growth rate (in %) of area, production and yield of rabi rice in the districts of Odisha

Figure 2 shows the graphical presentation of instability index of area, production and yield of rabi rice for different districts of Odisha.

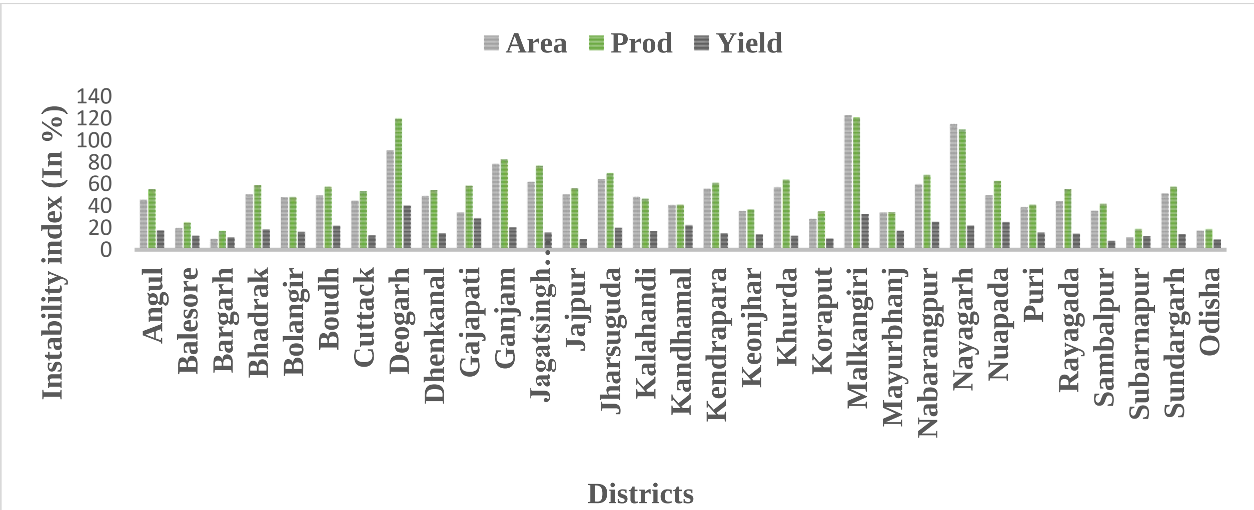

Fig. 2: Multiple bar diagram showing the instability index (in %) of Area, Production, Yield of rabi rice in the districts of Odisha

Table 3 shows the grouping of the districts of Odisha based on compound growth rate and instability index of area of rabi rice. Only Bargarh and Subarnapur showing positive growth rate with insignificant instability index.

Table 3: Grouping of the Districts of Odisha based on Compound Growth rate and Instability index of area of rabi rice

1A	Angul, Bhadrak, Cuttack, Deogarh, Dhenkanal, Ganjam, Jagatsinghpur, Jajpur, Kendrapara, Keonjhar, Khurda, Mayurbhanj, Nayagarh, Sundargarh
1B	No districts
2A	Balesore, Gajapati, Kalahandi, Koraput, Malkangiri, Nuapada,
2B	Bargarh, Subarnapur
3A	Bolangir, Boudh, Jharsuguda, Kandhamal, Nabarangpur, Puri, Rayagada, Sambalpur,
3B	No districts

1A= negative growth rate and significant instability

1B = negative growth rate and non-significant instability

2A= positive growth rate and significant instability

2B=positive growth rate and non-significant instability

3A = non-significant growth rate and significant instability

3B = non-significant growth rate and non-significant instability

Table 4 shows the grouping of the districts of Odisha based on compound growth rate and instability index of production of rabi rice. 40% districts showing positive growth rate and significant instability index.

Table 4: Grouping of the districts of Odisha based on compound growth rate and instability index of production of rabi rice

1A	Angul, Bhadrak, Cuttack, Dhenkanal, Jagatsinghpur, Jajpur, Kendrapara, Khurda, Nayagarh, Sundargarh
1B	No districts
2A	Balesore, Bargarh, Bolangir, Boudh, Gajapati, Kalahandi, Koraput, Malkangiri, Mayurbhanj, Nuapada, Rayagada, Subarnapur
2B	No districts
3A	Deogarh, Ganjam, Jharsuguda, Kandhamal, Keonjhar, Nabarangpur, Puri, Sambalpur
3B	No district

1A - negative growth rate & significant instability

1B = negative growth rate & non-significant instability

2A= positive growth rate & significant instability

2B=positive growth rate & non-significant instability

3A = non-significant growth rate & significant instability

3B = non-significant growth rate & non-significant instability

Table 5 shows the grouping of the districts of Odisha based on compound growth rate and instability index of yield of rabi rice. Most of the districts showing positive growth rate with significant instability index while 4 districts showing positive growth rate with non-significant instability.

Table 5: Grouping of the districts of Odisha based on Compound Growth rate and Instability index of Yield of rabi rice

1A	Nuapada
1B	No districts
2A	Balesore, Bolangir, Boudh, Cuttack, Dhenkanal, Gajapati, Ganjam, Jagatsinghpur, Jharsuguda, Kalahandi, Keonjhar, Khurda, Malkangiri, Puri, Rayagada, Subarnapur, Sundargarh
2B	Bargarh, Jajpur, Koraput, Sambalpur
3A	Angul, Bhadrak, Deogarh, Kandhamal, Kendrapara, Mayurbhanj, Nabarangpur, Nayagarh
3B	No districts

Conclusion:

As the study has analyzed the growth rate and instability index of rabi rice in all districts of Odisha, which shows there are several fluctuations in the growth pattern of area, production and yield of rice in most of the districts. It is again revealed that the area under rice have decreasing growth rate in many districts except in Kalahandi, Malkangiri, Nuapada, Koraput, Rayagada, Sambalpur, Boudh, Bolangir, Balesore and Bargarh. However, the production of rice has shown wide variation across districts as well as Odisha. There are 33% districts which shows positive growth rate in production. The varying performance of rabi rice at districts level has indicated the need for evolving specific strategies for ensuring sustainable and inclusive growth rate.

The instability in area, production of rabi rice for the districts are higher than that of the state. This shows that though in individual districts the instability in area, yield and production is high but when considered for the entire state they result in comparatively more consistency.

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HORMONE SIGNALLING IN PLANT DEFENSE

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Introduction:

In the natural environments, plants are under continuous biotic stress caused by different attackers (e.g., bacteria, fungi, viruses, oomycetes, and insects) that compromise plant survival and offspring. Given that green plants are the ultimate source of energy for most organisms, it is not surprising that plants have evolved a variety of resistance mechanisms that can be constitutively expressed or induced after pathogen or pest. Plants have developed molecular mechanisms to detect pathogens and pests and to activate defence responses. The plant innate immune system relies in the specific detection by plant protein recognition receptors (PRRs) of relatively conserved molecules of the pathogen called pathogen-associated molecular patterns (PAMPs). This resistance response is known as PAMP-triggered immunity (PTI). Successful pathogens secrete effector proteins that deregulate PTI. To counteract this, plant resistance (R) proteins recognize effectors and activate effector-triggered immunity (Dodds and Rathjen, 2010). Hence, the timely recognition of an invading microorganism coupled with the rapid and effective induction of defense responses appears to make a key difference between resistance and susceptibility. Plants produce a wide variety of hormones, which include auxins, gibberellins (GAs), abscisic acid (ABA), cytokinins (CKs), salicylic acid (SA), ethylene (ET), jasmonates (JA) and brassinosteroids (BRs). Among them, jasmonate (JA) and salicylic acid (SA) are major defense-related phytohormones (Shigenaga and Argueso, 2016). Other phytohormones, such as ethylene (ET), abscisic acid (ABA), auxin, gibberellins (GAs), cytokinins (CKs), and brassinosteroids (BRs), are also involved in defense responses. The identification and characterization of several mutants affected in the biosynthesis, perception and signal transduction of these hormones has been instrumental in understanding the role of individual components of each hormone signaling pathway in plant defense. Substantial progress has been made in understanding individual aspects of phytohormone perception, signal transduction, homeostasis or influence on gene expression. Microbial pathogens have also developed the ability to manipulate the defense-related regulatory network of plants by producing phyto hormones or their functional mimics. This results in hormonal imbalance and activation of inappropriate defense responses (Robert-Seilaniantz *et al*., 2007). For example, production of coronatine- a JA-Ile mimic by *Pseudomonas syringae pv. tomato* (Pst) bacteria, triggers the activation of JA-dependent defense responses leading to the suppression of SA-dependent defense responses and promotion of disease symptoms (Cui *et al.,* 2005).

Common signaling machinery

An oxidative burst, hormonal changes, and transcriptional reprogramming are triggered during PTI and ETI as common plant immune responses. Transcriptome analysis revealed that different MAMPs trigger induction of similar sets of genes, as does recognition of different effector proteins by Resistance (R) genes. Moreover, the sets of genes induced during PTI and ETI overlap (Zipfel *et al.,* 2006). In ETI, compensatory relationships among the signaling sectors dominate (Tsuda *et al.,* 2009). With high pathogen recognition specificity in ETI, strong immune signaling can be initiated at an early stage, and plants can afford to make the signaling sectors compensatory to one another at late stages.

Once plant defense responses are activated at the site of infection, a systemic defense response is often triggered in distal plant parts to protect these undamaged tissues against subsequent invasion by the pathogen. This long-lasting and broad-spectrum induced disease resistance is referred to as systemic acquired resistance (SAR) (Durrant and Dong, 2004) and is characterized by the coordinate activation of a specific set of *PR* genes, many of which encode for proteins with antimicrobial activity (Van Loon *et al.,* 2006). The onset of SAR can be triggered by PTI- and ETI-mediated pathogen recognition and is associated with increased levels of SA that act as a mobile signal and travels through the vascular system to activate defense responses, locally at the site of infection and often also systemically in distant tissues (Tsuda *et al.,* 2008). Mutant and transgenic plants that are impaired in SA signaling are incapable of developing SAR and do not show *PR* gene activation upon pathogen infection, which indicates that SA is a necessary intermediate in the SAR signaling pathway. Beneficial soil-borne microorganisms, such as mycorrhizal fungi and plant growth–promoting rhizobacteria, can induce a phenotypically similar form of systemic immunity called induced systemic resistance (ISR) (Pozo and Azcon, 2007). Like PAMPs of microbial pathogens, different beneficial microbe-associated molecular patterns are recognized by the plant, which results in a mild but effective activation of the immune response in systemic tissues (Vanwees *et al.,* 2008). In contrast to SA-dependent SAR, ISR triggered by beneficial microorganisms is often regulated by JA- and ET-dependent signaling pathways and is associated with priming for enhanced defense rather than direct activation of defense like PR genes. Whereas SAR is predominantly effective against biotrophic pathogens that are sensitive to SA-dependent defenses, ISR was shown to be effective against pathogens and insects that are sensitive to JA- and ET-dependent defenses (Van Oosten, 2008).

Major hormone signalling components

1. NPR1: The regulatory protein NPR1 (NONEXPRESSOR OF *PR* GENES1) emerged as an important transducer of the SA signal; upon activation by SA, NPR1 acts as a transcriptional co-activator of *PR* gene expression (Cui *et al*., 2015). The major mode of SA perception is explained by functions of NPR1 and its homologs, NPR3 and NPR4 (Seyfferth and Tsuda, 2014). NPR1 binds SA through Cys521/529 via the transition of the metal copper, which triggers a conformational change of NPR1, allowing transcriptional regulation, for example, through interactions with TGA-type transcription factors. NPR1 mediates SA-regulated suppression of JA and ABA signaling (Schmiesing *et al.,* 2016).

2. MYC2: MYC2 (originally called JIN1, for JASMONATE INSENSITIVE1) is a core transcriptional activator of JA signaling and MYC2 regulates JA-mediated suppression of *ICS1* and induction of genes for SA metabolism through transcriptional regulation of *SNAC-A* transcription factors in *A. thaliana.* Upon induction of the JA pathway, MYC2 differentially regulates two distinct classes of JA-responsive genes. MYC2 functions as a positive regulator of JA-responsive genes such as *VSP2* and *LOX2*, whereas it acts as a negative regulator of JA/ET-responsive genes such as *PDF1.2* that are activated by ERFs. Hence, when the JA response is activated. in combination with ET, the ERF branch of the JA response is activated, while the MYC2 branch of the JA response is activated when ET is absent. ABA was shown to play a role in favoring the MYC2- dependent branch of the JA response. MYC2 and its homologs MYC3 and MYC4 negatively regulate expression of *phytoalexin deficient 4* (*PAD4*), which contributes to SA accumulation. MYC2 activates expression of a gene essential for SA accumulation, *enhanced disease susceptibility 5* (*EDS5*), through direct binding to its promoter (Mine *et al.,* 2017).

3. JAZ and DELLA: JAZ (jasmonate ZIM-domain) proteins are repressors of JA signaling which have been shown (JAZ1 and JAZ3) to interact with JIN1/MYC2 and inhibit the expression of JA-responsive genes. JA (more specifically JA-Ile) promotes interaction between JAZ proteins and the SCFCOI1 ubiquitin ligase, leading to the ubiquitination and subsequent degradation of JAZ proteins by the 26S proteasome. The degradation of JAZ proteins allows transcription factors (such as MYC2) to activate the expression of JA responsive genes. In the absence of GA, DELLAs interact with JAZs in *A. thaliana*. This mediates a GA-JA antagonism as opposed to the GA-JA synergy. DELLA degradation upon GA perception releases JAZs that in turn suppress JA-mediated responses, resulting in attenuation of immunity against necrotrophic pathogens and promotion of immunity against biotrophic and hemibiotrophic pathogens.

4. miR393: Auxin suppression often increases resistance against biotrophic and hemibiotrophic pathogens. In *A. thaliana*, bacterial flagellin perception leads to suppression of auxin signaling through reduction of the auxin receptor transcript *TIR1*, which is mediated by the microRNA miR393. miR393 is induced in response to flagellin, and its overexpression results in increased resistance (Navarro *et al.,* 2006).

5. Gretchen Hagen 3 Family: Members of the Gretchen Hagen 3 (GH3) family of acyl acid amido synthetases modulate immunity and growth through changing the balance of active hormones. They conjugate amino acid residues to several phytohormones. For instance, *A. thaliana* JAR1 (GH3.11) conjugates isoleucine to jasmonic acid. In *A. thaliana*, WES1 (GH3.5) inactivates auxin by conjugating it to aspartic acid. Thus, GH3 family members are conserved hubs for hormone networks that modulate various phytohormone levels in immunity and growth.

Signaling pathways mediated by these phytohormones intimately interact antagonistically or synergistically. This regulatory logic determines the outcome of downstream responses activated by phytohormones. Hormonal interactions collectively form hormone signaling networks, which mediate immunity as well as growth and abiotic stress responses. The importance of hormone signaling networks in defense is reflected by the fact that many pathogens interfere with hormone signaling or produce hormones that increase virulence (Shigenaga and Argueso, 2016).

Roles of phytohormones in plant defense

1. Salicylic Acid (SA): SA is a phenolic hormone shown to affect many plant processes including growth, development, senescence, and stress responses. It is primarily recognized for its role in local defense induced against biotrophic and hemibiotrophic pathogens and in the establishment of SAR. Plants synthesize SA via two pathways: the phenylalanine ammonium lyase (PAL) pathway and the isochorismate (IC) pathway, both of which utilize chorismate, the end product of the shikimate pathway, as a precursor. The PAL pathway operates in the cytosol, and the IC pathway operates in chloroplasts. Mutation or silencing of *isochorismate synthase 1* (*ICS1*), which encodes a key enzyme of the IC pathway in *A. thaliana*, tomato, tobacco, and soybean, leads to the loss of pathogen-triggered SA production. Interestingly, silencing of *PAL* genes also results in the loss of SA induction upon pathogen infection in soybean. The importance of these SA biosynthesis pathways is reflected by the fact that the effector Cmu1 from the fungal pathogen *Ustilago maydis* degrades chorismate via the chorismate mutase activity, thereby reducing host SA production and promoting pathogen virulence. Other genes identified as direct targets of NPR1 include WRKY transcription factors and components required for the synthesis and secretion of PR proteins. Pathogen infection causes increased SA accumulation in eudicots such as *A. thaliana*, strawberry, pepper, and potato, although this does not appear to be the case in monocots. However, exogenous application of SA or its analog benzothiadiazole (BTH) triggers immune responses and resistance against biotrophic and hemibiotrophic pathogens in both eudicots and monocots (Sugano *et al.,* 2013).

2. Jasmonates: JAs are a group of lipid-derived hormones that regulate plant defense against necrotrophic pathogens and insect herbivores and also affect several other physiological processes including abiotic stress responses, reproductive development, and primary and secondary metabolism. Jasmonoyl isoleucine (JA-Ile) is perceived by a co-receptor complex consisting of the F-box protein CORONATINE INSENSTIVE 1 (COI1) and the JASMONATE ZIM DOMAIN (JAZ) family of transcription repressors. COI1 is required for almost all known JA-dependent responses. The JAZ-family proteins repress JA signaling by directly binding to the MYC family of transcription factors required for the expression of JA-responsive genes. Under normal growth conditions where JA-Ile levels are low, JAZ proteins recruit co-repressors, TOPLESS (TPL) or TPL-related proteins, either directly through their ETHYLENE RESPONSE FACTORASSOCIATED AMPHIFILIC REPRESSION (EAR) motifs or indirectly through NOVEL INTERACTOR of JAZ (NINJA) protein to suppress

MYC activities. JA biosynthesis is required for immunity against necrotrophic pathogens in many angiosperm species. In addition to necrotrophic pathogens, JA is associated with herbivore defense in multiple angiosperms, such as *A. thaliana*, maize, poplar, *Picea sitchensis*, *Nicotiana attenuata*, and *M. truncatula* (Howe and Jander, 2008).

3. Abscisic Acid (ABA): ABA plays important roles in plant defense responses. However, the role of ABA in plant defense appears to be more complex, and vary among different types of plant-pathogen interactions. In general, ABA is shown to be involved in the negative regulation of plant defense against various biotrophic and necrotrophic pathogens. ABA activates stomatal closure that acts as a barrier against bacterial infection. As a result, ABA deficient mutants show more susceptibility to *Pst*. In addition, treatment with ABA protects plants against *A. brassicicola* and *P. cucumerina* indicating that ABA acts as a positive signal for defense against some necrotrophs. In contrast, mutants deficient in ABA are more sensitive to infection by the fungal pathogens *A. brassicicola, Pythium irregulare* (Adie and Perez, 2007).

4. Auxins: Auxins are a group of molecules including IAA (indole-3-acetic acid) that regulate many aspects of plant development, such as apical dominance, root gravitropism, root hair, lateral root, leaf, and flower formation, and plant vascular development. Both direct and indirect effects of auxins on the regulation of pathogen resistance responses in plants have been described. Indirect effects may be caused by auxins regulation of development-associated processes, such as cell wall architecture, root morphology, and stomata pattern. For example, treatment of rice with IAA impaired the resistance to *Xanthomonas oryzae* pv. *oryzae* probably as a consequence of the activation of the biosynthesis of cell wall-associated expansions that lead to cell wall loosening, which facilitates pathogen growth. Auxins can negatively impact plant defense by interfering with other hormone signaling pathways or with PTI. The bacterial PAMPflg22, a peptide from flagellin protein induces an *Arabidopsis* microRNA (miR393), which negatively regulates them RNA levels of auxins receptors TIR1 (transport inhibitor response1), AFB2 (auxin signalling F-box 2), and AFB3. Thus, the flg22-triggered suppression of auxin signalling leads to increased resistance to the bacterium *Pseudomonas syringae* pv. *tomato* DC3000 (*Pst*DC3000) and also to the oomycete *Hyaloperonospora arabidopsidis*. The flg22-induced resistance to these biotrophic pathogens was explained by the observed induction of the SA signalling pathway.

5. Ethylene (ET): ET plays diverse physiological roles in plant growth and development and in stress responses in land plants. ET is synthesized from the enzymatic conversion of *S* adenosyl methionine to 1-amino-cyclopropane-1-carboxylic acid (ACC) by ACC synthase (ACS) and subsequently to ET by ACC oxidase. ET is perceived by multiple receptors that include ethylene response 1 (ETR1) in the endoplasmic reticulum membrane, which activates the key component ethylene insensitive 2 (EIN2). Upon activation, the C-terminal part of EIN2 is cleaved and moves into the nucleus, where it activates the transcription factor ethylene insensitive 3 (EIN3). ET contributes positively and negatively to immunity depending on the pathogen, environmental conditions, and plant species. For instance, in soybean, ET insensitivity increases severity of disease caused by the necrotrophic fungus *Rhizoctonia solani*, whereas enhanced *ACS2* expression promotes resistance against *R. solani* in rice (Helliwell *et al.,* 2013).

6. Cytokinins (CKs): Cytokinins (CK) are plant hormones involved in diverse processes including stem-cell control, vascular differentiation, chloroplast biogenesis, seed development, growth and branching of root, shoot and inflorescence, leaf senescence, nutrient balance and stress tolerance. Although, the role of CK in plant defense is poorly understood, there are indications that CK is involved in the regulation of plant defense responses against some pathogens. CK plays an important role in the development of club root disease caused by *Plasmodiophora brassicae* in *Arabidopsis*. Transgenic plants overexpressing cytokinin oxidase/dehydrogenase genes showed resistance against *P. brassicae* infection suggesting that cytokinin acts as a key factor in the development of clubroot disease in *Arabidopsis*.

7. Gibberellins (GAs): GAs are tetracyclic diterpene acids that control seed development and germination, vegetative growth, and flower initiation and development (Sun, 2011). Gibberellin (GA) was originally identified as a substance secreted from the fungus *Gibberella fujikuroi*, which causes 'bakanae' (or foolish seedling) disease in rice. GA promotes plant growth by stimulating degradation of negative regulators of growth called DELLA proteins. GA induces gene expression by relieving the repression of a family of transcriptional repressors known as DELLA proteins. In the absence of bioactive GAs, DELLAs bind to and inactivate PHYTOCHROME INTERACTING FACTORS (PIFs), a group of bHLH-family transcription factors (Sun, 2011). The presence of a growth signal stimulates the biosynthesis of GA, which is perceived by GA INSENSTIVE DWARF 1 (GID1) through direct binding. This leads to a conformational change of GID1, facilitating its binding to DELLA proteins.

8. Brassinosterods (BRs): Brassinosteroids (BRs) are a unique class of plant hormones that are structurally related to the animal steroid hormones and involved in the regulation of growth, development and various physiological responses in plants. Although, BRs are known to influence various developmental processes including seed germination, cell division, cell elongation, flowering reproductive development, senescence, and abiotic stress responses in plants. BRs are involved in the regulation of plant defense responses. BR was shown to increase the resistance of rice plants against *M. grisea* and *Xanthomonas oryzae* infection. However, BR induced resistance does not require SA biosynthesis and activation of PR gene expression indicating that BR mediated resistance is independent of SA mediated defense signaling in plants. Exogenous application of 24-epibrassinolide, a BR, was shown to prevent the development of disease symptoms on tomato plants inoculated with *Verticillium dahliae*, whereas untreated plants showed moderate to severe disease symptoms (Krishna, 2003). Similarly, BR sprayed potato plants showed resistance to infection by *Phytophthora infestans* and this resistance was found to be associated with increases in the levels of ABA and ET (Krishna, 2003).

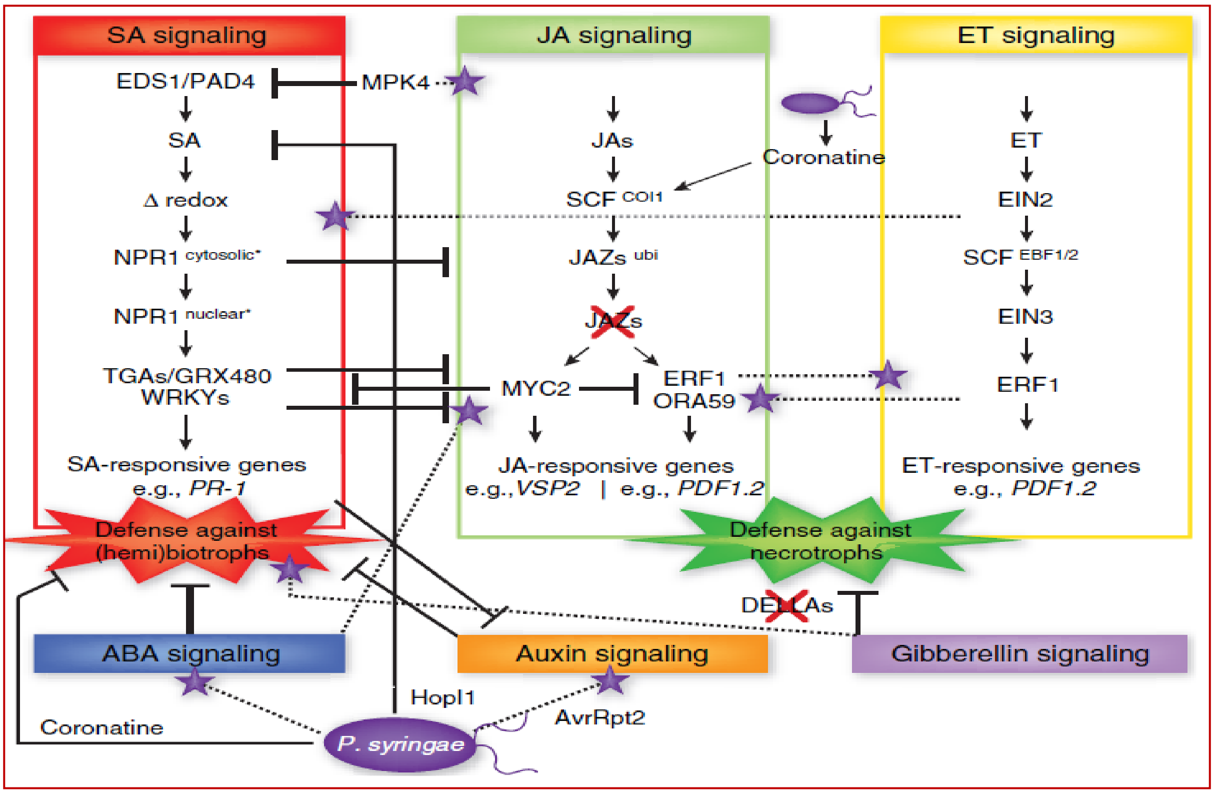
Signalling networks:

(**a**) SA mediates a change in the cellular redox potential, resulting in the reduction of the NPR1 oligomer to its active monomeric form. Monomeric NPR1 is then translocated into the nucleus where it functions as a transcriptional co-activator of SA-responsive genes, such as *PR-1*, by enhancing the binding of TGA transcription factors to SA-responsive promoter elements (Loake and Grant, 2007).

(**b**) In the JA signaling cascade, the E3 ubiquitin ligase SCFCOI1 complex and jasmonate ZIM-domain (JAZ) proteins form a complex that represses transcription of JA-responsive genes. Upon accumulation of JA, JA-isoleucine (JA-Ile) binds to the F-box protein COI1 in the SCFCOI1 complex, after which the JAZ proteins are ubiquitinated and subsequently degraded through the 26S proteasome. This results in the activation of JA-responsive genes through the action of transcription factors such as MYC2, ERF1 and ORA59 (Pre, 2008).

(**c**) In the ET signaling cascade, the gaseous hormone ET is perceived by plasma membrane receptors such as ETR1. Genetically, these receptors are negative regulators of the ET response, because in the absence of ET they maintain the negative regulatory role of CTR1, which represses the positive regulator EIN2. Upon perception of ET, the repression of ET signaling by CTR1 is relieved, allowing downstream signaling through EIN2. Subsequently, critical positive regulators of ET-responsive gene expression, such as EIN3, become active because the E3 ubiquitin ligase SCFEBF1/2-dependent 26S proteasome degradation of these proteins becomes inhibited. EIN3-like transcription factors activate transcription factors such as ERF1, resulting in the expression of downstream ET-responsive genes (Kendrick and Chang, 2008).

Cross-communication between hormone signaling pathways provides the plant with a large regulatory capacity that may tailor its defense response to different types of attackers. On the other hand, pathogens such as *P. syringae* produce effector proteins (for example, coronatine, HopI1 and AvrRpt2) that manipulate the signaling network to suppress host immune responses and promote virulence. The SA, JA and ET signaling pathways represent the backbone of the defense signaling network, with other hormonal signaling pathways feeding into it.



1. Hormone cross talk in combined stress:

Hormone cross talk is an effective way to integrate multiple stimuli to coordinate sophisticated physiological responses. The existence and conservation of hormone cross talk are assumed to bring fitness advantages to plants simultaneously exposed to multiple stresses (Vos *et al.,* 2015). Experiments in *A. thaliana* have shown that when attacked by herbivores and pathogens of different lifestyles, plants indeed experience hormone cross talk, as measured by changes in hormone-regulated gene expression. The absence of any observed fitness reduction (i.e., growth alterations) under these conditions can be interpreted as a consequence of hormone cross talk, allowing plants to activate specific rather than general defense responses, thus conserving resources that can be used for growth (Vos *et al.,* 2015). In the particular case of abiotic stress, ABA lowers plant immunity through cross talk with immune-related hormonal pathways. Such cross talk likely evolved to modulate the activation of immune responses during adverse abiotic conditions encountered by plants upon land colonization. For example, conditions of drought are likely to signal a lower probability of pathogen attack, as increased humidity is necessary for sporulation and spore germination in most biotrophic and necrotrophic fungi and oomycetes and is essential for bacterial survival and spread. Thus, the mostly negative cross talk of ABA on SA- and JA-regulated defense responses is likely a response to lower defense activation when a pathogen attack is not imminent. In addition, because activated immunity lowers abiotic stress responses, negative ABA effects on JA and SA signaling can enhance abiotic stress responses, which may be necessary to increase survival of certain plant species in severe abiotic stress conditions (Mosher *et al.,* 2010).

2. Decoy Strategies by Pathogens: Effectors are proteins secreted by pathogens during infection to deregulate host immune responses. One common strategy implemented by effectors is the manipulation of the homeostasis of plant phytohormones, resulting in deactivation of the appropriate defense response (Bari and Jones, 2009).

3. Bacteria and phytoplasma: In addition to the common example of the phytotoxin COR produced by *P.syringae* strains to manipulate the plant hormonal balance, many phytopathogenic bacteria have developed large repertoires of type III effectors (T3E) which are necessarily injected through the syringe-like type III secretion sys- tem inside plant cells to deregulate plant immunity. *Xanthomonas* spp. bacteria synthesized TAL (transcription activator like) effectors, such as AvrBs3 from *X. axonopodis* pv. *vesicatoria* (formerly *X. campestris* pv. *vesi-catoria*), that are imported to the plant nuclei where they activate the expression of host target genes. Five targets, designed as up-regulated by AvrBs31to5 (UPA1–5), are auxin-induced genes members of the SAUR (small auxin up RNA) family. Additionally, induction of the TAL target *UPA20* provokes cell hypertrophy, a feature which is characteristic of auxin accumulation (Kay *et al.,* 2007).

Auxin signalling seems to be a preferential target of phytoplasmas, some bacteria like, obligate plant pathogens belonging to the class of Mollicutes that require sap-feeding insect herbivores as vectors for transmission to plants. Indeed, TENGU (tengu-su inducer) is an effector of *Candidatus phytoplasma asteris* that, when expressed in *Arabidopsis* transgenic lines, causes dwarfism and abnormal reproductive organogenesis and flower sterility. These phenotypes, which are similar to the disease symptoms provoked by the phytoplasma, have been associated to alterations in hormone balance. Microarray analysis of transgenic *Arabidopsis* plants expressing TENGU demonstrated that many auxin-related genes were down-regulated, including genes of the *Aux/IAA*, *SAUR*, *GH3*, and *PIN* families (Hoshi *et al*., 2009). Thus, TENGU effector could interfere with auxin signaling in plants.

Filamentous pathogens- oomycetes and fungi:

Oomycete genomes contain a class of cytoplasmic proteins known as RXLRs that contain a conserved RXLR amino acid motif. Two effectors from this class, HaRxL96 from *Hyaloperonospora arabidopsidis*, the causal agent of downy mildew on *Arabidopsis*, and its ortholog PsAvh163 from *Phytophthora sojae*, which causes soybean rot disease, interfere with plant immunity. Remarkably, *Arabidopsis* plants expressing HaRxL96 or PsAvh163 became more susceptible to virulent and avirulent pathogens, indicating that these effectors repress basal resistance and ETI. Infact, the induction of SA-defensive genes, but not SA biosynthesis, that take places upon infection with avirulent strains of *Hyaloperonospora arabidopsidis*, was suppressed in the transgenic lines expressing HaRxL96 or PsAvh163, indicating that these effectors interfere with SA signalling to trigger plant susceptibility to oomycetes (Anderson *et al.,* 2012).

U. maydis is a basidiomycete fungus that causes smut disease on maize and its relative teosinte. Maize infection by *U. maydis* results in the repression of SA-associated *PR1* defense gene expression during the early biotrophic phase of the interaction, while auxin production in the host is induced later during tumor formation. One of the most highly expressed genes of *U. maydis* during plant colonization is the Cmu1effector, a chorismate mutase protein. Cmu1 is required for full virulence since the induction of tumors is significantly reduced in a *U. maydis cmu1* mutant. Once inside plant cells, Cmu1 is localized in the cytoplasm, the nucleus and guard cells and it is spread to neighbour cells through plasmodesmata. A yeast two-hybrid analysis showed that Cmu1 interacts with two maize chorismate mutases, ZmCm1 and ZmCm2, which are found in plastids and cytoplasm in plants, respectively. Interestingly, SA levels were higher in maize inoculated with a *cmu1* mutant than with a wild-type strain, resulting in an increased resistance of the mutant to *U. maydis*. It was hypothesized that Cmu1 could act together with ZmCm2 in the plant cytoplasm to enhance the flow of the SA-precursor chorismate from the plastid (where SA biosynthesis takes place) to the cytosol. Consequently, in plastids, less chorismate would be available for SA biosynthesis (Djamei *et al*., 2011). These results indicate that SA biosynthesis pathway of maize is hijacked by *U. maydis* as a mechanism of virulence.

Conclusion:

- Plant hormones regulate complex signaling networks involving developmental processes and plant responses to environmental stresses including biotic and abiotic stresses.
- Depending on the type of plant–pathogen interactions, different hormones play positive or negative roles against various biotrophic and necrotrophic pathogens.
- Signaling pathways cross-communicate in an antagonistic or synergistic manner, to finely regulate immune response.

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ENVIRONMENTAL POLLUTION

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Virtually any human endeavor that leads to the deterioration or decline in the quality of the natural environment is categorized as pollution. Environmental pollution, although not a recent occurrence, remains one of humanity's most critical global challenges. It stands as a prominent contributor to illnesses and fatalities worldwide. In 2015, it was projected that pollution-related health issues were responsible for a staggering 9 million premature deaths, a toll exceeding the combined fatalities caused by malaria, AIDS, and tuberculosis (Landrigan *et al.,* 2017). Typically, environmental pollution is more pronounced in middle- and low-income nations compared to developed ones. This disparity may arise from factors such as poverty, inadequate legislation, and a lack of awareness regarding pollution forms. Conceivably, humans might encounter pollution in their daily lives without recognition, or perhaps have grown desensitized to it due to the fast pace of modern living (Muralikrishna and Minicab, 2017). Ironically, a lack of awareness about various pollution forms leads individuals to engage in activities that yield harmful byproducts in quantities that overwhelm the environment's ability to restore balance, potentially leading to irreversible system changes. Activities like deforestation, burning vegetation, improper waste disposal in water sources, chemical usage in aquatic harvesting, and inappropriate disposal of electronic waste all contribute to air, soil, and water pollution. Furthermore, as human populations rise, so does the intensity of environmentally impactful activities, affecting not only humans but also aquatic and terrestrial life, including microorganisms. The latter's abundance and diversity are crucial for maintaining the ecosystem's biogeochemical functions. The causes of environmental pollution go beyond industrialization, urbanization, population growth, and resource exploitation. They encompass the transboundary movement of pollutants between developed and developing nations, aggravating the global pollution challenge. Through various channels, primarily air and water, pollution generated in one country can wreak havoc in another, necessitating a collective global effort. Moreover, the international transfer of non-functional electronic equipment under the pretext of bridging the digital divide perpetuates air, water, and soil pollution due to toxic metals. Additionally, environmental pollution arises from the release of harmful substances like gaseous pollutants, toxic metals, and particulate matter into the atmosphere. Water bodies suffer from contamination due to sewage, industrial discharges, agricultural runoff, and improper waste disposal, while soil pollution is fueled by mining, deforestation, landfills, and illegal dumping. It's not uncommon for individuals to overlook the connection between human actions and the destabilization of the natural environment, leading to practices that induce severe diseases and fatalities. In middle- and low-income nations, detrimental activities persist due to weak legislation enforcement, limited penalties, or a lack of acknowledgment regarding their health and environmental impacts. The ramifications of environmental pollution, particularly air pollution, are deeply concerning, disproportionately affecting vulnerable groups like low-income earners, children, the elderly, and others in developing countries.

Understanding the causes and repercussions of environmental pollution holds significant importance, yet the consequences of not taking action are substantial. Various physical and chemical methods have been employed to combat pollution in the environment, but many of these solutions inadvertently lead to additional environmental issues and are financially demanding. In the pursuit of addressing pollution stemming from persistent and challenging pollutants, the literature increasingly emphasizes the exploration of eco-friendly and cost-effective approaches that minimize the production of secondary byproducts. Among these strategies, microbial bioremediation has gained global attention due to its potential for environmentally sustainable restoration. While diverse forms of pollution exist, this discussion will primarily focus on the three principal categories: air pollution, water pollution, and soil/land pollution.

Major types of pollution

Air pollution

Air pollution refers to the presence of toxic chemical compounds in the atmosphere, occurring at concentrations that pose risks to animals, plants, humans, and structures. It encompasses the introduction of foreign chemical substances into the air, leading to a decline in air quality. This pollution has far-reaching effects, influencing not only the environment but also human lives, contributing to global warming and ozone layer depletion. The characteristics, distribution, and impacts of pollutants differ based on their source, form, and generation conditions. Notable gaseous pollutants include sulfur oxides (particularly SO_2), nitrogen oxides (including NO and NO_2), volatile organic compounds

(VOCs), and carbon monoxide (CO). These pollutants are categorized as primary and secondary pollutants. Primary pollutants (e.g., CO, CO_2, NO_2, and SO_2) are directly released into the atmosphere from sources like industries, transportation, and households. In contrast, secondary pollutants arise from the transformation of primary pollutants within the atmosphere, giving rise to substances such as atmospheric nitrogen oxide gases, sulfuric acids, and ozone (O_3) as examples.

The extent of harm induced by air pollutants hinges on their chemical properties such as oxidizing potential, solubility, concentration, and the vulnerability of affected entities. For instance, water-soluble gases like SO_2 can harm skin and upper respiratory passages, while less soluble gases like O_3 and NO_2 can penetrate deeper into the lungs. CO, a colorless, odorless gas, possesses high solubility and easily enters the bloodstream, binding to hemoglobin and forming carboxyhemoglobin, leading to adverse effects. Particulate matter (PM) is typically categorized by size: PM10 denotes particles with a diameter of 10 µm or less, PM 2.5 represents particles with a diameter of 2.5 µm or less, and PM0.1 signifies particles with a diameter of 0.1 µm or less. Larger visible particles, carried by wind, can deposit on surfaces and in human eyes. Various health-detrimental pollutants such as polyaromatic hydrocarbons (PAHs) and persistent organic pollutants (POPs) are often present in emissions from incomplete combustion of organic materials. These pollutants can attach to PM, traveling long distances before depositing on the environment, causing severe harm. Consequently, air pollution is recognized as one of the most critical forms of pollution, with widespread implications for both the environment and human well-being.

Water pollution

Water pollution originates from both anthropogenic (human-made) and natural origins. Groundwater sources, for instance, can naturally contain ores rich in toxic metals, which subsequently seep into water bodies, leading to pollution. Notable cases involve elevated levels of arsenic and lead contamination in groundwater, directly associated with these naturally occurring ores. Moreover, as highlighted by Ewuzie *et al.* (2020), the geological formations in various regions significantly influence the elemental makeup of water bodies. Consequently, these geological factors might be accountable for heightened concentrations of elements that contribute to water pollution.

Human activities contribute significantly to water pollution through various sources. These anthropogenic origins encompass contamination from household waste, the use of insecticides and herbicides, improper disposal of waste from food processing, pollutants stemming from livestock farming, volatile organic compounds (VOCs), heavy metals leaching from electronic waste, chemical waste, and medical waste. Airborne pollutants like particulate matter (PM) can also introduce additional organic pollutants into surface water bodies. The consequences of such pollutants can manifest as health issues for humans, including symptoms like stomachaches, vomiting, diarrhea, and diseases like typhoid.

Chemicals such as pesticides, hydrocarbons, persistent organic pollutants (POPs), and heavy metals hold the potential to induce detrimental health effects such as cancer, disruptions in hormonal balance, reproductive impairment, and severe damage to the liver and kidneys. Moreover, the presence of nutrients in water can lead to a phenomenon known as eutrophication, where excessive plant and sometimes algae growth occurs. This can ultimately deplete oxygen levels, exacerbating pollution issues within aquatic ecosystems.

Soil pollution

Aside from natural events like earthquakes and erosion, which can lead to soil damage, the primary contributors to soil contamination are industrial and domestic waste. Various soil pollutants include heavy metals, hydrocarbons, inorganic and organic solvents. Soil pollution often results from practices such as improper waste disposal on open land, waste incineration, and inadequate landfill management. Industries dealing with fossil fuels, such as petrochemical plants, petroleum refineries, and power generation facilities, significantly contribute to soil pollution. The entire lifecycle of petroleum, from exploration to refining and transportation, can lead to soil contamination.

Recently, the global spotlight has turned towards the pollution of land by plastics. This concern arises from the toxic additives used in plastic production and the direct impact plastics have on plants and animals. Plastic litter on land not only disrupts aesthetics but also has the potential to penetrate into the soil, impeding nutrient uptake by plants and causing entanglement of terrestrial animals.

The ramifications of soil pollution extend beyond human health issues to affect metabolic processes in plants, leading to reduced crop yields. Additionally, pollutants can enter the food chain through absorption by plants, creating further concerns about the safety of the food supply.

Causes of environmental pollution

Urbanization and industrialization

Since the onset of the industrial revolution, humanity has been introducing hazardous substances into the environment at an alarming pace. This trend, driven by industrialization, urbanization, and economic growth, yields a complex web of both positive and negative effects on the environment. Across many countries, urbanization and rapid economic expansion coincide with a notable migration of populations from rural areas to urban centers. However, uncontrolled urbanization in developing nations often leads to environmental degradation, triggering a host of interconnected problems, including heightened air pollution, water contamination, waste management challenges, and the degradation of agricultural lands.

While industrialization, modernization, and urban growth contribute to environmental pollution on a global scale, their impact is particularly pronounced in developing countries. Water resources are under pressure, and as populations expand, the risk of further depletion or complete drying up grows due to neglect of water conservation and wasteful water consumption. Pollution further exacerbates this situation, rendering water bodies non-potable. Additionally, the discharge of industrial waste into land and water bodies is overwhelming. Rapid urbanization and industrial growth result in substantial amounts of wastewater, toxic sludge, heavy metals, and solvents entering rivers and streams, causing significant pollution.

Urbanization has amplified the proliferation of automobiles and motor vehicles, posing a significant threat to air quality through increased air pollution. Furthermore, industrialization's pursuit has fueled habitat destruction through activities like deforestation for lumber, road construction, and housing development. This destructive process has severe consequences, leading to ecosystem disruption and the potential extinction of various plant and animal species.

Mining and exploration

Mining and exploration processes give rise to a spectrum of pollution, affecting air, water, and land quality to varying extents. The level of pollution hinges on the specific phase and scale of activities conducted at the site. The mere excavation of a mining site can lead to waste accumulation, the formation of sinkholes, and habitat loss. Particularly in mining for valuable materials like gold ore, the process can release other harmful elements such as lead (Pb), causing both soil and water pollution.

While mineral exploration might contribute to minor pollution, the various stages of extensive exploration tend to result in more pronounced soil, water, and air pollution. This pollution becomes even more substantial when it emanates from large-scale exploitation of resources like rocks, petroleum, and limestone used in construction projects. In certain African nations rich in oil reserves, illegal activities such as bursting oil pipelines and unauthorized oil refining have become prevalent. Despite attempts by security agencies to suppress these practices by burning down illegal refineries, this action generates substantial amounts of carbon compounds, sulfur compounds, organic pollutants, and toxic metals. These emissions have severe repercussions not only for the environment but also for terrestrial and aquatic ecosystems. The consequences range from the occurrence of acid rain and heightened heat due to greenhouse gas presence, to the demise of aquatic life in surface waters.

Cement factories and mining operations in limestone quarries can introduce significant quantities of dust into the atmosphere, further contributing to environmental pollution.

Agricultural activities

Agriculture plays a pivotal role in driving economic development and sustaining livelihoods in any nation. Despite its significance, agricultural activities can still be a source of pollution, posing various health and environmental risks. Pollution stemming from agriculture arises due to specific farming practices that harm, contaminate, and degrade both the environment and ecosystems.

Burning waste materials from agricultural operations, such as land clearing, overusing fertilizers, and utilizing non-biodegradable pest control chemicals, is a key source of pollution in farming. These actions introduce chemical substances into the food chain, generate smoke and particulate matter, and disrupt habitats. Additionally, nitrates originating from agricultural processes are recognized chemical pollutants in groundwater aquifers. The excessive application of fertilizers, beyond what plants require, often leads to eutrophication in water bodies. This phenomenon, characterized by an excess of nutrients, is frequently linked to the misuse of fertilizers that exceed the plants' uptake capacity. Excessive nitrogen and phosphates can leach into surface water or groundwater through runoff.

Beyond the pollution arising from land cultivation, the rearing of terrestrial or aquatic animals also contributes to environmental contamination. For example, uneaten animal feeds and animal excreta can produce strong odors with potential health implications. Moreover, the pursuit of greater agricultural output to sustain a growing global population has driven the use of antifouling agents, antibiotics, and fungicides in farming, further exacerbating ecosystem pollution.

While agriculture is essential for human sustenance and food production, the pollution resulting from agricultural activities warrants significant concern. Balancing the need for agricultural productivity with environmentally responsible practices is of paramount importance.

Burning of fossil fuels

Fossil fuels can release harmful air pollutants even before they are burned. Once burned, these fuels emit a range of air pollutants, contributing to environmental pollution and the degradation of ecosystems. The utilization of fossil fuels like oil, coal, and gas to meet our energy demands has driven the ongoing crisis of global warming. The act of burning these fuels releases a mixture of primary and secondary pollutants, resulting in a cascade of environmental consequences.

The emissions arising from the combustion of fossil fuels encompass a spectrum of substances, including airborne particles, sulfur dioxide (SO2), carbon dioxide (CO2), carbon monoxide (CO), hydrocarbons, organic compounds, various chemicals, and nitrogen oxides (NOx). Notably, fossil fuel emissions contain significant quantities of major greenhouse gases, such as carbon dioxide, methane (CH_4), nitrous oxide, and fluorinated gases. Consequently, the air pollution stemming from these activities not only poses a threat to air quality but also plays a significant role in driving climate change and global warming. The intricate link between fossil fuel combustion, air pollution, and its contribution to broader environmental challenges underscores the urgent need for transitioning to cleaner and more sustainable energy sources.

Particulate matter

Particulate Matter (PM) is a significant component of the atmosphere, comprising tiny particles suspended in the air. PM can originate from both natural and human activities. A range of natural sources introduces substantial amounts of PM into the atmosphere. These include volcanic eruptions, wind and dust storms, forest fires, salt spray from oceans, rock debris, chemical reactions between gaseous emissions, and soil erosion. These natural processes collectively release millions of tons of PM into the air. On the other hand, human activities contribute significantly to PM emissions as well. Various man-made actions involving the combustion of fuels, industrial operations, steel production, petroleum refining, cement and glass manufacturing, smelting, mining activities, fly-ash emissions from power plants, coal burning, and the incineration of agricultural waste all play a role in introducing PM into the atmosphere. These activities collectively contribute to the levels of PM that are present in the air. The sources of both natural and human-made PM emphasize the need for proactive measures to mitigate the environmental and health impacts associated with elevated PM concentrations in the atmosphere.

Plastics

The realization of plastics' substantial contribution to environmental pollution is growing among the public. Various types of plastics, including polypropylene, polyethylene, polystyrene, polyamides, and polyesters, can be found in the natural environment. In many developing countries, plastic bags are commonly used for shopping and storing food due to their durability and affordability. Additionally, plastic bottles have replaced glass bottles for packaging beverages. However, the indiscriminate disposal of these plastic bottles after consumption adds to the growing accumulation of plastics in the environment. While plastics are mostly non-biodegradable, they can break down into larger macro- or smaller microplastics.

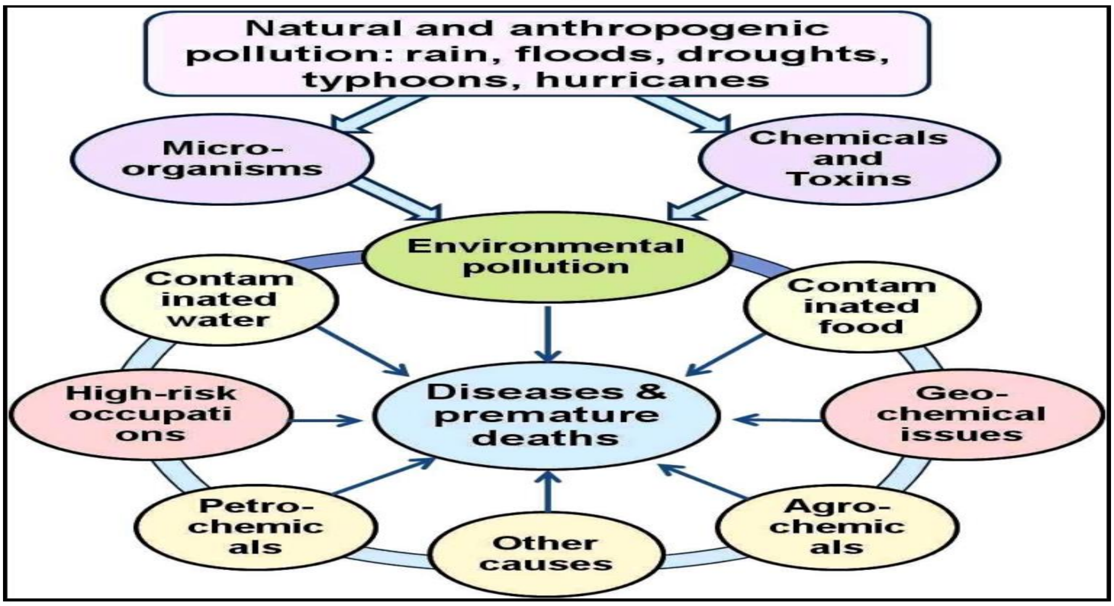
Remarkably, the generation of plastic waste has surged over the years. For instance, between 1960 and 2013, the growth of municipal solid waste generation in the United States was 188%, whereas plastic waste generation increased by a staggering 82.38% (Tsiamis *et al.*, 2018). This growth in plastic waste generation coincided with a decline in waste generation from glass and metal materials. Microplastics (MPs) are particularly prevalent in consumer goods like paints, cosmetics, and synthetic clothing fibers that are released during washing. Additionally, secondary MPs emerge from the fragmentation of larger plastic debris (Auta *et al.*, 2017). Most of the plastic debris found on the surface falls within the range of microplastics (0.33 to 4.75 mm). The pollution caused by microplastics is recognized as a significant threat to coastal marine environments. However, ongoing research aims to uncover the environmental consequences of microplastics in terms of their distribution, concentration, and characteristics. The full extent of their impact is still being explored.

Effects of environmental pollution

The adverse impacts of environmental pollution are often inadequately documented, particularly in many developing countries that bear the brunt of pollution's effects. This disparity arises from unreliable database management systems and a general lack of awareness regarding the harmful consequences that pollution can have on both the environment and human health. For instance, certain regions in Africa attribute health problems such as birth defects, miscarriages, cancer, stunted growth, and sudden deaths to misfortune or "acts of the gods." This attribution tends to divert attention away from pollution and its associated effects.

It's widely recognized that social determinants of health, including income and education levels, strongly influence public priorities concerning environmental protection. In lower-income countries, individuals tend to prioritize basic needs such as food and shelter over health and environmental preservation. This prioritization mismatch contributes to the exacerbation of pollution and its resulting impacts in these nations.

Addressing the issue of environmental pollution requires not only improving data collection and management systems but also raising awareness about the tangible and far-reaching consequences of pollution on both health and the ecosystem. Bridging the knowledge gap and fostering a deeper understanding of these issues can play a pivotal role in driving more concerted efforts toward environmental protection and sustainable development.



Effects on the environment

Environmental pollution earns its name due to the fact that the environment is often the primary casualty in the surge of pollution. The environment comprises land, water, atmosphere, and the biosphere, acting as a repository for all pollutants. The impacts of pollution are wide-ranging and impactful on various environmental components.

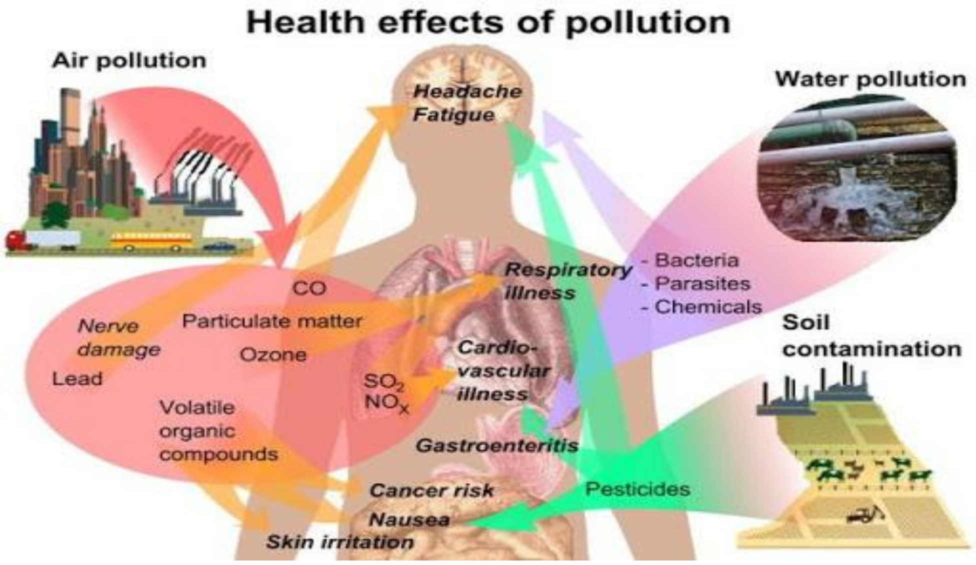
Regarding land, the effects include the unsightly littering of land surfaces with waste, leading to unpleasant odors and diminished aesthetics. Trees suffer damage, wildlife species face mortality, soil fertility declines causing poor plant yields, and even man-made structures like roofing sheets are negatively affected. Historical monuments and buildings are impacted, and vehicles can experience discoloration. Activities such as continuous mining damage vegetation and soil systems, ultimately reducing soil productivity and fertility. Other human actions result in landscape damage, including habitat destruction, soil erosion, animal extinction, and the depletion of resources like wetlands and coastal ecosystems. Chemical changes in soil properties occur, leading to the loss of essential nutrients like magnesium, potassium, and calcium, subsequently decreasing soil pH. These effects collectively contribute to food shortages for both humans and other animals, potentially leading to starvation and death.

The interaction between land and water enables the easy exchange of pollutants, with pollution's consequences on water bodies manifesting as changes in chemical, microbiological, and physical properties. Elevated water temperatures result from increased solar heat, oil exploration areas experience surface coverage preventing oxygen and sunlight penetration, drilling-related sodium chloride elevates water salinity, toxic metal content rises, and eutrophication can occur. These changes lead to excessive plant growth, reduced oxygen levels, diminished biodiversity, disruption of ecosystems, and overall deterioration of water quality and quantity. Water bodies lose their appeal, becoming malodorous and uninviting, often abandoned due to the influx of sulfur and nitrogen compounds and other anaerobic activities stemming from pollution.

Atmospheric air serves as a transporter of various pollutants, depositing them onto both water and land. When sunlight interacts with certain pollutants like particulate matter (PM) and gases, haze emerges, obscuring the clarity of objects. The effects of microplastics (MPs) on soil and aquatic environments are actively being studied. However, MPs may contain hazardous additives and chemicals that can infiltrate the soil ecosystem and accumulate in invertebrate animals. Such accumulation in creatures like earthworms can impact their immune responses, biomass, growth, and even reproduction.

Collectively, these environmental pollution effects intricately connect with human and animal health, underscoring the urgent need for comprehensive pollution management and environmental protection efforts.

Effects on human health



Could it be that the consequences of human activities have come full circle to haunt us? The impacts of pollution on human health are strikingly evident, with a majority of illnesses traced back to environmental pollution. Current research is uncovering mounting evidence linking pollution to various severe health conditions. Among these studies, those investigating the health implications of air pollution exposure are proliferating at an alarming rate.

The World Health Organization's report underscores the significance of indoor air pollution caused by cooking and heating fires, attributing 3.8 million deaths to this factor (WHO, 2018). Predictably, this figure varies from 10% in middle- and low-income countries to 0.2% in high-income countries. Furthermore, the Global Burden of Disease study revealed that a component of outdoor air pollution, specifically particulate matter with an aerodynamic diameter of 2.5 micrometers (PM2.5), ranked as the fifth leading risk factor for global deaths. This factor was responsible for 4.2 million deaths and over 103 million disability-adjusted life years lost in 2015 (Schraufnagel *et al.*, 2018).

Evidence indicates a connection between shortened newborn telomere length and maternal exposure to pollutants like PM2.5, PM10, carbon monoxide (CO), and sulfur dioxide (SO2) during the third trimester of pregnancy (Song *et al.*, 2019). This suggests that these pollutants not only pose threats to our immediate health but also pose serious and sensitive hazards to the unborn. Occasionally, pollution's impact on this vulnerable demographic becomes pronounced and persists throughout their lifetimes. Persistent organic pollutants (POPs) and polyaromatic hydrocarbons (PAHs), both recalcitrant pollutants, have been found to bind with particulate matter, particularly PM2.5, resulting in various cardiopulmonary diseases, respiratory ailments, cancer, and non-cancer effects in humans. Airborne pollutants tend to travel greater distances and cause more widespread damage as they reach the population through breathing, settling on drinking water, or contaminating exposed foods.

Several other health issues stemming from pollution may still be undiscovered, yet epidemiological studies are increasingly linking various women's health problems to pollution, especially air pollution. Research suggests that exposure to PM2.5 and ozone (O3) could induce specific genetic or epigenetic abnormalities, leading to the development of conditions like uterine fibroids (Lin *et al.*, 2019). These findings underscore the need for comprehensive pollution control measures to safeguard both human health and the environment.

Effects on animal health

Oil spills occurring during exploration, refining, and transportation, whether on land through pipelines or marine vessels, impose sub lethal health effects on both wildlife and marine organisms. These spills introduce harmful substances contained within petroleum products into the environment, affecting the digestive, respiratory, and circulatory systems of these organisms. Inhalation or ingestion of these substances by marine life leads to negative impacts. Seabirds and other marine mammals face the peril of oil slicks that adhere to their skin or feathers, impeding their movement, hampering their ability to find sufficient food, and leaving them vulnerable to predators. Oil spills present a severe threat to seabirds, often underreported. Research demonstrates that birds are succumbing to the effects of oil fouling. While some oil-fouled birds are discovered and reported upon death, the extent of unreported deaths due to oil spill effects remains high (Walker *et al.*, 2019).

The challenges posed by plastic pollution have recently gained significant attention. Plastics damage ecosystems, curtail biodiversity, and ultimately endanger various marine creatures, including birds, fish, crabs, turtles, and other marine animals (Barboza *et al.*, 2019). Plastics impact animals directly and indirectly. Direct harm encompasses problems stemming from ingestion, leading to internal damage, lacerations, lesions, choking, and entanglement of aquatic organisms. Primary producers in the food chain, like algae, experience hindered growth and photosynthesis, while crustaceans face developmental and reproductive challenges (Barnes, 2019). Aside from immediate fatality, injuries can occur, restricting movement and potentially causing starvation or rendering escape from predators difficult. Moreover, these organisms are indirectly affected by additives used in plastic production, such as plasticizers and other organic pollutants, which alter metabolic processes and behaviors.

Pollution's effects extend to genetic variability and biodiversity within natural populations. Research indicates that fish living in polluted environments exhibit highly intricate ribosomal sequences in their genomes. An increase in the number of copies of ribosomal DNA occurs systematically, responding to variations in environmental conditions. This phenomenon arises as these sequences play a crucial role in maintaining genome integrity (Araújo da Silva *et al.*, 2019). The intricate interplay between pollution and the natural world's genetic makeup highlights the need for vigilant environmental stewardship and conservation efforts.

Effects on microorganisms

Microscopic communities within flowing water ecosystems, including zooplankton, hold critical importance in the intricate processes of nutrient cycling and energy transfer within aquatic food webs (Xiong *et al.*, 2019). As a result, the health of these ecosystems can be accurately gauged by studying the biological reactions of these microorganisms to their environmental circumstances. Unfortunately, pollution has exerted a substantial impact on the geographic distribution of zooplankton biodiversity, thereby diminishing their effectiveness in fulfilling their ecological roles.

Remedies

Numerous methods for pollution remediation have been proposed, encompassing biological, chemical, and physical approaches. However, the key emphasis should be on preventing pollution at its source to facilitate swift and feasible remediation of already impacted environments. Physical methods for soil reclamation don't alter the physicochemical properties of pollutants present in the environment, whereas chemical methods break down accumulated pollutants and modify their properties to reduce ecological harm. Notably, biological methods leverage the activity of microorganisms and higher plants to degrade pollutants, leading to their mineralization, immobilization, or removal.

The implementation of Agenda 2030, "Transforming our World: the 2030 Agenda for Sustainable Development," is recommended. This framework aims to shape a more sustainable future for humanity and the responsible utilization of the natural resources we rely upon (Barboza *et al.*, 2019). Recent research suggests specific areas for exploration and innovation, such as understanding and minimizing plastic usage, cleaning up oceans and beaches, developing alternative materials, and comprehending the impacts on human and animal health (Barnes, 2019).

Conclusion:

This chapter has provided an encompassing overview of pollution, delving into its origins, repercussions, and potential remedies. Amidst the various pollution categories, air pollution has garnered significant attention and research, likely due to its pronounced impact on morbidity and premature mortality rates. Both developed and developing nations grapple with the burdens of pollution, yet the latter face more severe consequences due to inadequate regulations, lack of awareness, and economic challenges. Vulnerable populations in middle- and low-income countries bear the brunt of pollution's effects disproportionately. It is imperative to heighten awareness regarding the perils of pollution, and concerted efforts from all sectors are necessary to curtail activities leading to environmental contamination. By preventing pollution at its root, the prospect of remediating already affected environments becomes achievable. Among the array of potential solutions, biological methods involving microorganisms have gained recognition as eco-friendly, cost-effective, and sustainable approaches that safeguard both the environment and human well-being.

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MINERAL NUTRITION OF P IN PLANT

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Introduction:

Phosphorus is one of 17 nutrients essential for plant growth. Its functions cannot be performed by any other nutrient, and an adequate supply of P is required for optimum growth and reproduction. Phosphorus is classified as a major nutrient, meaning that it is frequently deficient for crop production and is required by crops in relatively large amounts. The total P concentration in agricultural crops generally varies from 0.1 to 0.5 percent of a plant's dry weight, where it is primarily a component of tissue molecules such as nucleic acids, phospholipids and adenosine triphosphate (ATP). After (N), P is the second most limiting nutrient. It can reduce plant growth and development and potentially limit crop yield. However, excess P in soil can be detrimental to the environment because it can enter freshwater bodies through surface runoff and can cause algal bloom reducing water quality. Improved P management can create profitable crop production systems systems while reducing negative impact on the environment. The objectives of this documents is to understand P function in plant, forms, transformation and cycling in soil, P fertilizers, P solubilizers mechanisms in the soil. P cycle is unique and different from the N cycle because P does not exist in gaseous form. This document provides basic information on the various forms of P basic information on the various forms of P present in the soil and the process that affect P availability for crop production.

Function of P in plant

1. **Plant energy reactions**: Phosphorus plays a vital role in virtually every plant process that involves energy transfer. High energy phosphate, held as a part of the chemical structures of adenosine diphosphate (ADP) and ATP, is the source of energy that drives the multitude of chemical reactions within the plant. When ADP and ATP transfer the high energy phosphate to other molecules (termed phosphorylation), the stage is set for many essential processes to occur.
2. **Photosynthesis:** The most important chemical reaction in nature is photosynthesis. It utilizes light energy in the presence of chlorophyll to combine carbon dioxide and water into simple sugars, with the energy being captured in ATP. The ATP is then

available as an energy source for the many other reactions that occur within the plant, and the sugars are used as building blocks to produce other cell structural and storage components.

3. **Genetic transfer**: Phosphorus is a vital component of the substances that are building blocks of genes and chromosomes. So, it is an essential part of the process of carrying the genetic code from one generation to the next, providing the "blueprint" for all aspects of plant growth and development. An adequate supply of P is essential to the development of new cells and to the transfer of the genetic code from one cell to another as new cells are formed. Large quantities of P are found in seeds and fruit where it is believed essential for seed formation and development. Phosphorus is also a component of phytin, a major storage form of P in seeds. About 50 percent of the total P in legume seeds and 60 to 70 percent in cereal grains is stored as phytin or closely related compounds. An inadequate supply of P can reduce seed size, seed number, and viability.
4. **Nutrient transport**: Plant cells can accumulate nutrients at much higher concentrations than are present in the soil solution that surrounds them. This allows roots to extract nutrients from the soil solution where they are present in very low concentrations. Movement of nutrients within the plant depends largely upon transport through cell membranes, which requires energy to oppose the forces of osmosis. Here again, ATP and other high energy P compounds provide the needed energy.

- **Deficiency symptoms of P**: Phosphorus deficiency symptoms are often subtle, but plants may develop dark green or purple coloration of leaves and stems, and be shorter with delayed leaf emergence, slower development, reduced tillering, lower dry matter yield and reduced seed production.

Transformation of P in soil

- **Forms of soil P**

  A. Organic phosphorus

  a) Inositol phosphates

  b) phospholipids

  c) nucleic acids.

  d) sugar phosphates, phytic acid, polyphosphates, and phosphonates etc.

B. Inorganic phosphorus

The inorganic P can be further divided into different pools.

a) Soil solution P

b) Labile soil phosphorus

c) Non labile P

1. Soil solution P: Phosphorus is absorbed by plants largely as primary and secondary orthophosphate ions $H_2PO_4^-$ or HPO_4^{2-}. The amount of each form is dependent on soil pH. Very little P is present in soil solution.

2. Labile soil phosphorus: is the readily available portion of the total P compared to non-labile P and it has a high dissociation rate, permitting rapid replenishment of solution phosphorus. Depletion of labile P causes non labile P to be labile again, but at a very slow rate. Phosphorus bound to aluminum (Al:P), iron (Fe:P) and calcium (Ca:P) constitutes the major active labile form of inorganic P. The Fe:P and Al:P constitute 1:25 % of total P in soils. The Ca:P constitutes 40:50% or even more of total P in neutral to alkaline soils.

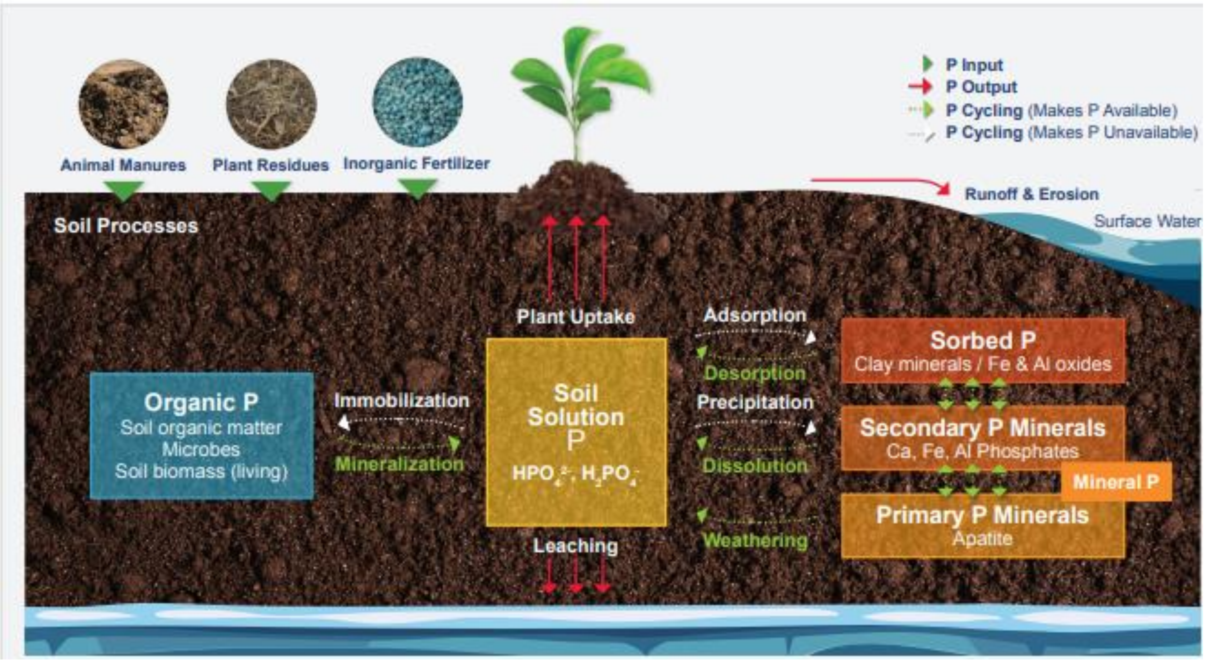


Figure 1: Soil phosphorous cycle. This figure illustrates the source of P inputs in the soil, pathway through which P becomes available/unavailable for plant uptake and P outputs/loss pathways

3. Non labile P: The relatively less active non labile forms. Soils naturally contain P-rich minerals are non:labile P. This pool is comprised of primary and secondary phosphate minerals present in soil. Examples of primary phosphorous minerals include apatite, strengite and variscite. The secondary P minerals include Ca, Fe and Al phosphate. The release of P from this pool is extremely slow and occurs when the minerals weathers and dissolve in soil water.

The general P transformation processes are:

- Weathering and precipitation, mineralization and immobilization, and adsorption and desorption.
- Weathering, mineralization and desorption increase plant available P.
- Immobilization, precipitation and adsorption decrease plant available P.

1. **Weathering**: Soils naturally contain P:rich minerals, which are weathered over long periods of time and slowly made available to plants.

   Primary minerals

   Flourapatite: 3 Ca_3 $(PO_4)_2$ CaF

   Carbonate apatite: 3 Ca_3 $(PO_4)_2$ $CaCO_3$

   Hydroxy apatite: 3 Ca_3 $(PO_4)_2$ $CaCO_3$

   Secondary minerals

   Fe and Al containing P compounds

   Strengite – Fe PO_4. 2 H_2O

   Vivanite - Fe $(PO_2)_4$. 8 H_2O

   Variscite – Al PO_4. 2 H_2O

   Wavellite – Al_3 $(OH)_3$ (PO_4). 5 H_2O

2. **Precipitation:** Precipitation is the process of conversion of a solution into solid by converting the substance into insoluble form. Phosphorus can become unavailable through precipitation, which happens if plant available inorganic P reacts with dissolved iron, aluminum, manganese (in acid soils), or calcium (in alkaline soils) to form phosphate minerals.

3. **Mineralization and immobilization**

• Mineralization is the microbial conversion of organic P to $H2PO4^-$ or $HPO4\ 2^-$, forms of plant available P known as orthophosphates.

• Mineralize soil organic P by the production of phosphatases and phytase enzymes that hydrolyze organic forms of phosphate compounds, thereby releasing inorganic phosphorus.

• The commonly reported phosphatases and phytase producing fungus and bacteria are: *Aspergillus candidus, Aspergillus fumigatus, Aspergillus niger, Bacillus, Pseudomonas, Penicillium rubrum, Penicillium simplicissimum.*

• Immobilization occurs when these plant available P forms are consumed by microbes, turning the P into organic P forms that are not available to plants. The microbial P will become available over time as the microbes die.

• Maintaining soil organic matter levels is important in P management. Mineralization of organic matter results in the slow release of P to the soil solution during the growing season, making it available for plant uptake. This process reduces the need for fertilizer applications and the risk of runoff and leaching that may result from additional P.

4. Adsorption and desorption

• Adsorption is a process in which phosphorus present in soil solution is attached/bound to the surface of soil particles. The phosphorus binding takes place on clay surfaces or the iron (Fe) and aluminum (Al) oxides and hydroxides present in soil.

• Adsorption is a fast process and reversible in nature, meaning that adsorbed phosphorus can be released into soil solution (reverse) a process known as desorption and will be available for plant uptake.

• Adsorption (or "fixing" as it is sometimes called) occurs quickly whereas desorption is usually a slow process.

• Adsorption differs from precipitation: adsorption is reversible chemical binding of P to soil particles while precipitation involves a more permanent change in the chemical properties of the P as it is removed from the soil solution.

• Soils that have higher iron and/or aluminum contents have the potential to adsorb more P than other soils.

Phosphorus loss

Phosphorus is removed from soil by

(a) crop/plant uptake,

(b) runoff and erosion, and

(c) leaching.

• Surface runoff is the major pathway for phosphorus loss from soils. Runoff water carries away both soluble (dissolved) phosphorus and particulate (eroded soil particles) phosphorus from soil surface.

• Leaching is the loss of soluble phosphorus from sub:surface soil as water percolates vertically down the soil profile. In general, phosphorus loss by leaching is minimal compared to surface runoff.

In addition, phosphorus availability in soil solution is influenced by the following factors:

1. **Organic matter**. Organic matter is an important factor in controlling phosphorus availability. With the addition of organic matter, availability of phosphorus increases.

   • **This is due to the following reasons:**

   • Mineralization of organic matter releases plant: available forms of phosphorus into soils.

   • Organic molecules will compete with phosphate adsorbed to soil surfaces and will reduce phosphorus retention. This process will increase availability of phosphorus.
2. **Clay content.** Soils with higher clay content have high phosphorus retention capacity because clay particles have very large surface area per unit volume, which can adsorb phosphorus easily.
3. **Soil mineralogy.** The mineral composition of the soil influences the phosphorus precipitation capacity. For example, soils with a high content of Al3+ and Fe3+ also tend to have the greatest phosphorus precipitation.
4. **Soil pH:** Optimum soil pH between 6 and 7 will result in maximum phosphorus availability. At low pH (acidic soils), soils have greater amounts of aluminum and iron, which form very strong bonds with phosphate. At high pH when calcium is the dominant cation, phosphate tends to precipitate with calcium.

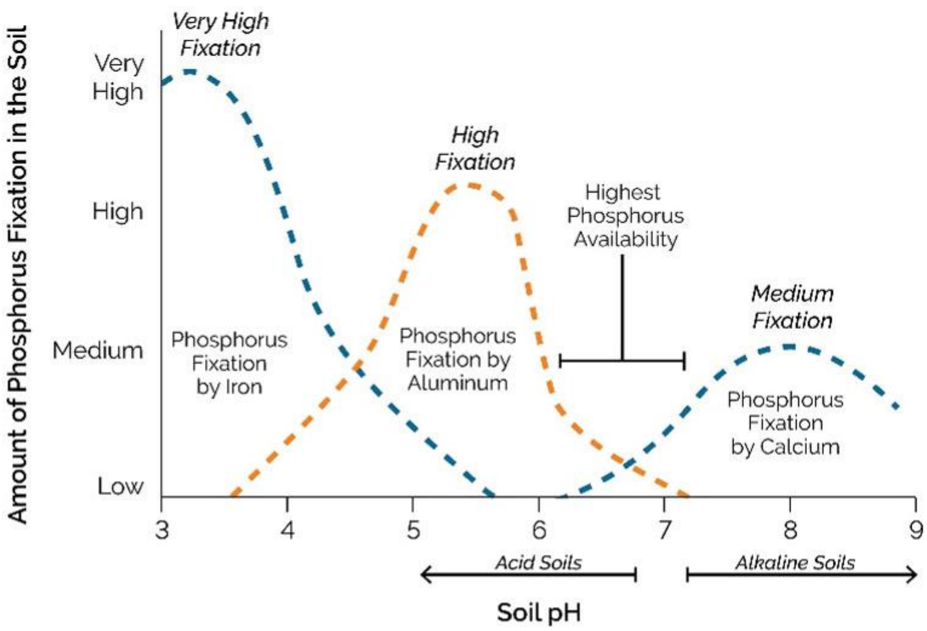


Figure 2: Effect of pH on phosphorous availability

5. **Other factors:** Temperature, moisture, and soil aeration can affect the rate of P mineralization from organic matter decomposition. For example, in warm, humid climates organic matter decomposes faster compared to cool dry climates.

Phosphatic fertilizers

Salt of the PO_4^{3-} ion; phosphate rock containing a high proportion of tricalcium serving as fertilizer or raw material for the manufacture of fertilizer. The plant nutrient content of all phosphatic fertilizers expressed in percentage of phosphorus pentaoxide (P_2O_5).

- **Classification of phosphatic fertilizer:** The phosphatic fertilizers are classified on the basis of the form in which phosphoric acid is combined with calcium and their solubility in water and weak acids. On the basis of above parameters phosphatic fertilizers are classified into three groups which are as follows.
  1. Water soluble phosphatic fertilizers or monocalcium phosphate
  2. Citric acid soluble phosphatic fertilizers or dicalcium phosphate
  3. Water and citric acid insoluble phosphatic fertilizers or tricalcium phosphate

1. Water soluble phosphatic fertilizers or monocalcium phosphate: Contain P in available form. Few fertilizers belong to this group are	
Single superphosphate	16 -18% P_2O_5
Double superphosphate	32% P_2O_5
Triple superphosphate	46 - 48% P_2O_5
Ammonium phosphate	20% N +20% P_2O_5 or 16%N +20% P_2O_5
2. Citric acid soluble phosphatic fertilizers or dicalcium phosphate:	
Basic slag	14 - 18% P_2O_5
Dicalcium phosphate	34 - 39% P_2O_5
Rhenania phosphate	23 - 26% P_2O_5
Raw and steamed bone meal	Part of P_2O_5 soluble in citric acid
3. Water and citric acid insoluble phosphatic fertilizers or tricalcium phosphate	
Rock phosphate	20 - 40% P_2O_5
Raw bone meal	20 - 25% P_2O_5 & 3 – 4%N
Raw and steamed bone meal	22% P_2O_5

Facts of the phosphatic fertilizer:

- Water soluble phosphatic fertilizers or monocalcium phosphate should be used on neutral to alkaline soils only.
- Citric acid soluble phosphatic fertilizers or dicalcium phosphate are well for lateritic and acidic soils.
- Water and citric acid insoluble phosphatic fertilizers or tricalcium phosphate are well suited for strongly acidic soils or organic soils which requires more phosphatic fertilizer to raise the soil fertility.
- **Composition and properties of major phosphatic fertilizer**: The phosphatic fertilizer viz superphosphate, bone meal, basic slag and rock phosphate are the major fertilizer used in India. Composition and properties of major phosphatic fertilizers are as follows.

1. **Single superphosphate**: It is the oldest artificially produced fertilizer, first manufactured dates back to 1842. Brief specification of single superphosphate as prescribed in the Fertilizer Control Order, 1957 is as follows:

Parameters Content	**Parameters Content**
Moisture per cent by weight, maximum	12
Free phosphoric acid (as P_2O_5), per cent by weight, maximum	4
Water soluble phosphate (as P_2O_5), per cent by weight, minimum	16

Note: Single superphosphate Grade II contain 14% P_2O_5 and other parameters remains same as single superphosphate.

General properties of single superphosphate fertilizer:

a) It is a greyish fertilizer.

b) In our country, single superphosphate is manufactured in both granular and powdered from.

c) To ensure sufficient supply of phosphorus to the plant in its early growth period and to minimize P fixation, entire quantity of recommended dose should be applied just before sowing of the crop.

d) As P is immobile in soil that is why even water-soluble superphosphate has also to be applied in the root zone of the plant.

e) Due to its slow mobility super phosphate is unsuitable for top dressing.

f) Superphosphate should not be used on the acidic soil (pH <5.5).

2. Bone-meal: Bone-meal considered as oldest phosphatic fertilizers. It is of two type one is raw or untreated bone-meal another is bone: meal steamed.

a. Raw or untreated bone-meal: Brief specification of raw or untreated bone-meal as prescribed in the Fertilizer (Control) Order, 1957 is as follows.

Parameters	Content
Moisture per cent by weight, maximum	8.0
Acid insoluble matter, per cent by weight, maximum	12.0
Total phosphates (as P_2O_5), per cent by weight, maximum	20.0
Phosphates (as P_2O_5) soluble in 2% citric acid solution, per cent by weight, minimum	8.0
Nitrogen content of water insoluble portion, per cent by weight, minimum	3.0

b. Steamed bone-meal: Bone-meal steamed is different than raw one as former one sterilized with steam and dried in rotating warm oven to make it brittle to facilitate easy grinding. Brief specification of steamed bone-meal as prescribed in the Fertilizer (Control) Order, 1957 is as follows.

Parameters	Content
Free moisture per cent by weight, maximum	7.0
Total phosphates (as P2O5), per cent by weight	22.0
Phosphates (as P2O5) soluble in 2% citric acid solution, per cent by weight (on dry basis), minimum	16.0

General properties of bone-meal:

1. As it contains citrate soluble phosphate, found to be more suitable for acidic soil and long duration crop.

2. It should not be applied as top dressing rather applied before sowing or at the time of sowing.

3. It is comparatively expensive than other phosphatic fertilizer due to less production and its increasing demand for animal feed.

3. Basic slag: Basic slag is greyish black color powder. It is by-product of steel industry. Basic slags are of two type (1) Bessemer basic slag:high grade fertilizer contains citrate soluble 11:20% phosphoric acid (2) Open :Hearth basic slag contains less phosphorus than former one. In India low grade basic slag are produced which are not consumed as fertilizer on large scale. Basic slag as fertilizer is most suitable for acidic soil as it contains free unslaked lime (CaO). In comparison to rock phosphate and or bone-meal basic slag phosphorus is easily available to the plants. Alkaline nature and easy availability of its phosphorus to plants make it desirable phosphatic fertilizer.

4. Rock phosphate: Rock phosphate in basically used as raw material for manufacturing for other phosphatic fertilizer but in certain conditions it is also used as fertilizer. ICAR has recognized Mussoorie rock phosphate and Purulia rock phosphate for direct application. The following are the conditions which found to be conducive for direct application of rock phosphate.

i. Rock phosphate should be finely grounded to provide wider reaction surface.

ii. A strongly acidic soil should have high humus content.

iii. Long duration crop especially plantation crop such as tea, apple orange coffee etc. are more suitable for direct application of rock phosphate.

iv. Should be cheaper than water-soluble phosphatic fertilizer.

2. Phosphate solubilising microorganisms

- Though most soils contain appreciable amounts of inorganic P, most of it being insoluble forms, cannot be utilized by crops unless they are solubilized.
- Soil P is fixed as Fe: and Al:P in acid soils, Ca:P in alkaline soils. (These are inorganic form of P)
- Soils also contain organic P that could not be utilized by plants only when it is mineralized.
- Phosphate solubilizing microorganisms not only able to solubilize insoluble forms of inorganic P but are also capable to mineralize organic forms of P, thus improving the availability of native soil P making their P available to plants.
- PSM can also solubilize P from rock phosphate (RP), slag or bone meal making their P available to plants. Thus PSM biofertilizer being economical and environmentally safe offers a viable alternative to chemical fertilizers.

Mechanism of PSM for P solubilization

a) Lowering Soil pH

The principal mechanism for solubilization of soil P is lowering of soil pH by microbial production of organic acids or the release of protons.

These organic acids are the products of the microbial metabolism, mostly by oxidative respiration or by fermentation when glucose is used as carbon source.

In alkaline soils, phosphate can precipitate to form calcium phosphates.

Organic acids that solubilize phosphates are primarily citric, lactic, gluconic, 2-ketogluconic, oxalic, glyconic, acetic, malic, fumaric, succinic, tartaric, malonic, glutaric, propionic, butyric, glyoxalic, and adipic acid.

b) Production of CO_2

- PSMs are also known to create acidity by evolution of CO_2.
- Respiration by plant roots, bacteria, fungi and soil animals all release CO_2 in soils.
- Decomposers break down dead material from plants and other organisms and release carbon dioxide.
- Water and carbon dioxide combine to form carbonic acid (H_2CO_3), a weak acid that breaks (or "dissociates") into hydrogen ions (H^+) and bicarbonate ions (HCO_3^-). Hence P ions are released by substitution if H^+ for Ca^{2+} and increase solubilization of calcium phosphates.

a) Chelation

- Chelating agents are organic molecules that can trap or encapsulate certain metal ions like Ca, Mg, Fe, Co, Zn and Mn and then release these metal ions slowly so that they become available for plants to take them up.)
- Organic and inorganic acids produced hydroxyl and carboxyl groups (anions) of the acids chelate the cations bound to phosphate, thereby converting it into soluble forms.
- 2-ketogluconic acid is a powerful chelator of calcium.

b) Production of inorganic acids

- Such as sulphuric, nitric, and carbonic acid etc. Nitric and sulphuric acids react with calcium phosphate and convert them into soluble forms.

c) Mineralization

- Conversion of organic P in inorganic P is mineralization.
- Organic phosphate is transformed into utilizable form by PSM through process of mineralization.
- It occurs in soil at the expense of plant and animal remains, which contain a large amount of organic phosphorus compounds such as nucleic acids, phospholipids, sugar phosphates, phytic acid, polyphosphates, and phosphonates.

- PSMs mineralize soil organic P by the production of phosphatases like phytase enzymes that hydrolyze organic forms of phosphate compounds, thereby releasing inorganic phosphorus.
- The commonly reported phytase producing fungus: *Aspergillus candidus, Aspergillus fumigatus, Aspergillus niger, Aspergillus parasiticus, Aspergillus rugulosus, Aspergillus terreus, Penicillium rubrum, Penicillium simplicissimum, Pseudeurotium zonatum, Trichoderma harzianum, and Trichoderma viride.*

2. Mycorrhizae

- The Mycorrhizae derived from the Greek word, Mykes: Fungus and Rhiza: root meaning fungus root.
- Mycorrhizae are mushroom fungi that form symbiotic association of a fungus with the roots of higher plant.
- The plant makes organic molecules such as sugar by photosynthesis and supplies them to fungus in return the plant gains the benefits of the mycelium higher absorptive capacity for water and mineral nutrients because of large surface area of fungal hyphae which are much larger and finer than plant root hairs.
- 95% of the plant sp. form Mycorrhizae.

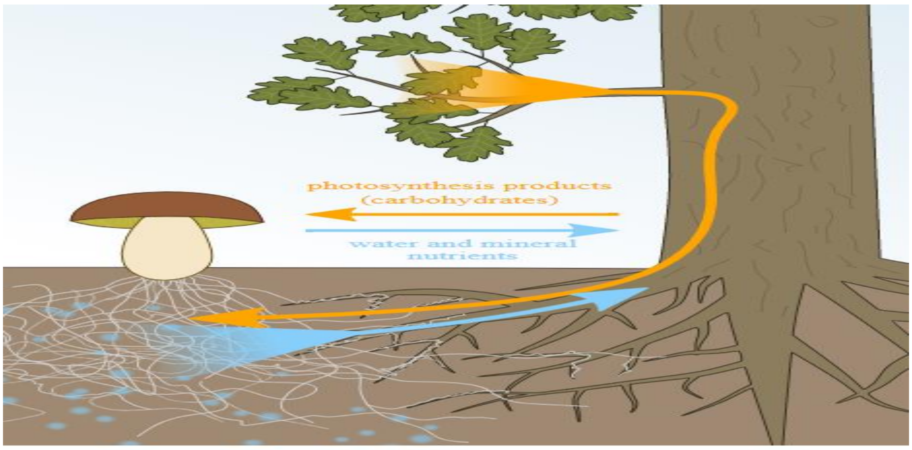
Mychorrhiza are commonly two types:

A. Ecto mychorrhiza

- This type of fungi does not penetrate individual cell within the root.
- Extensive network form called “harting net”.
- Harting net act as storage and transport organ for P and other nutrients.

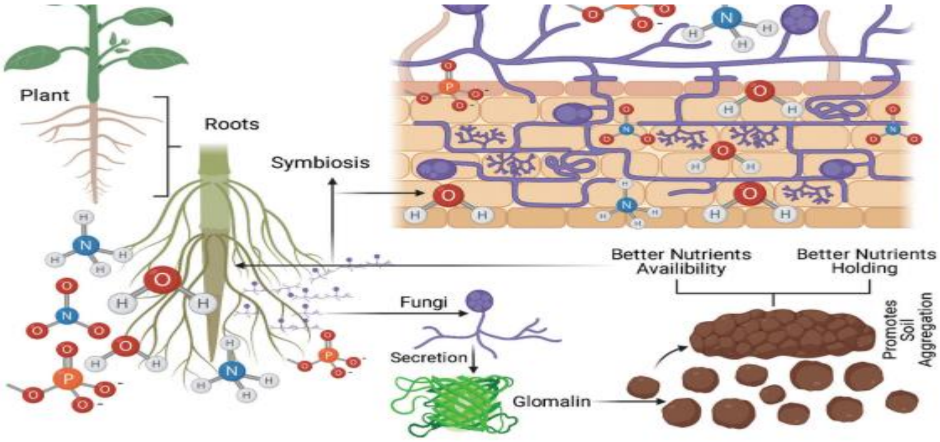
B. Endo mychorrhiza

- While the hyphae of endo mychorrhiza fungi penetrate the cell wall and invaginate the cell membrane.
- They provide internal network of hyphae.
- **Endo mycorrhizae form two structure**
- **Arbuscules**: are the fine branched hyphal helps in transfer of nutrient from fungus to the root system.
- **Vesicles**: Terminal or intercallery hyphal swellings act as a storage organ.
- It is also known as (VAM) vascular arbuscular mycorrhizae.



Advantages of mycorrhizae:

- Help absorb many nutrients for transmission to the plant, improve mineral nutrition especially P, Zn, Cu etc through mobilization.
- Because they provide a protective cover, mycorrhizae increase the plant tolerance to drought to high temperature, to infection by disease fungi and even to extreme soil acidity.



- Improved water retention.
- The hyphae of mycorrhizae produce the glomalin protein which increase soil aggregation and it is the major source of C in soil.
- Also contribute in carbon sequestration in soil reduce green house effect.

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IMPORTANCE OF SOIL HEALTH

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Abstract:

Soil health or soil quality is a concept that has increased in popularity over the past several years, especially since the early 1990s. It continues to gain traction among farming and ranching communities, soil managers, scientists, agricultural Extension specialists, and other groups that work with soil. "Soil health" is an important focus for many agricultural groups interested in regenerative and sustainable crop and livestock production as well as land management. While awareness of soil health is increasing, it is important to have a good understanding of what soil health entails, how it is measured, and how to manage it for optimal and sustainable delivery of the ecosystem services that soils provide. Keeping in this view present chapter deal with importance of soil health.

Keywords: Soil health, Conservation agriculture, no tillage, crop rotation, soil cover or mulch

Introduction:

To define soil health appropriately, we need to consider the words that form "soil health." "Soil" is defined by the Soil Science Society of America (SSSA) as "the unconsolidated mineral or organic material on the immediate surface of the earth that serves as a natural medium for the growth of land plants." "Health" is defined by Merriam-Webster as "the condition of being sound in body, mind, or spirit." We can restructure this definition of health to apply to the soil. Combined with the SSSA's definition of soil, "soil health" can be defined as "the state of the soil being in sound physical, chemical, and biological condition, having the capability to sustain the growth and development of land plants." There are many definitions of soil health; however, emphasis is always placed on the sustained ability of soil to provide services, such as production of crops and other agricultural products, retention and filtration of water, habitat for diverse organisms, and recycling of nutrients. Incorporating all these elements is a holistic definition of soil health as "the capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health". The complex biological, physical, and chemical interlink of a healthy soil can influence plant water availability under dry conditions, off-field nutrient losses to nearby streams during rain events, and the availability of nutrients through nutrient cycling for food and fiber production. Furthermore, healthy soils maintain or enhance water and air quality through the improvement of soil C storage and water infiltration, and support human health and wildlife habitat.

Healthy functioning soils

a) Produce food, fuel, fiber, and medicinal products.
b) Store, filter, and release water
c) Provide resilience to environmental disturbances.
d) Resist diseases, pests, and pathogens
e) Store and cycles carbon
f) Store and cycle nutrients internally
g) Maintain biodiversity and habitat.

Characteristics of a healthy soil

1. **Good soil tilth**- Soil tilth refers to the overall physical character of the soil in the context of its suitability for crop production.
2. **Sufficient depth**- Sufficient depth refers to the extent of the soil profile to which roots are able to grow and function. Shallow depth because of a compaction layer or past erosion is more.
3. **Sufficient but not excess supply of nutrients**

   a) An adequate and accessible supply of nutrients

   1) Optimal plant growth
   2) Maintaining balanced cycling of nutrients

   b) Excess nutrients can lead to

   1) Leaching
   2) Ground water pollution
   3) Toxicity to plants and microbial communities
4. **Small population of plant pathogens and insect pests**- In agricultural production systems, plant pathogens and pests can cause diseases and damage to the crop. I

   In a healthy soil, population of these organisms is low and/or inactive.

   In a unhealthy soil, population of these organisms is high and/or active.

   This could result from direct competition from other soil organisms for 1) Nutrients or niche 2) Habitats 3) Hyper parasitism.
5. **Good soil drainage**- Even after a heavy rain a healthy soil will:

   1) drain more rapidly – as result of good soil structure
   2) an adequate distribution of different size pore spaces

3) retain adequate water for plant uptake.

6. **Large population of beneficial organisms**- A healthy soil will have a high and diverse population of beneficial organisms to carry out these functions and thus help maintain a healthy soil status.

   Soil microbes are:

   1) functioning of the soil
   2) help nutrient cycling
   3) decomposition of organic matter
   4) maintenance of soil structure
   5) biological suppression of plant pests

7. **Low weed pressure**- Weed pressure is a major constraint in crop production. Weeds compete with crops for

   Constraint

   1) Weeds compete with crops for water and nutrients that are essential for plant growth. Weeds can interfere withstand establishment
   2) Block sunlight,
   3) Interfere with harvest and cultivation operations and
   4) Harbor disease causing pathogens and pests.

8. **Free of chemicals and toxins that may harm the crop**- Healthy soils are either devoid of harmful chemicals and toxins or can detoxify and/or bind such chemicals making them unavailable for plant uptake due to their richness in stable organic matter and diverse microbial communities.

9. **Resistant to degradation** A healthy, well aggregated soil is more resistant to adverse events including erosion by wind and rain, extreme drought, vehicle compaction.

Causes for reduction of soil health

1. Aggressive tillage-

Tillage creates a warmer, aerated, and competition-free environment for seed germination in the short term, but vigorous tillage fractures the soil, alters soil structure, and accelerates surface runoff and soil erosion in the long run. Splashed particles destroy soil pores, effectively blocking water infiltration and soil's surface. It's almost certain that the soil structure and quality will be completely degraded. A hardpan can form, stopping root elongation, crop development, and yield. Erosion depletes soil fertility by removing topsoil. Nearly all of the plant-available potassium, as well as half of the plant-available phosphorus, is concentrated in topsoil. Although producers can provide necessary crop nutrients to compensate for the loss of natural fertility, degraded soil productivity can only be restored by adding inputs if favourable subsurface material is present. There is little or no capacity to recoup yield losses in areas with adverse subsoils (low rooting depth, coarse sand and gravel, or high soil densities).

2. Annual/seasonal fallow-

Leaving soils barren and without an active root system can result in severe damage, not only in terms of potential soil erosion, but also in terms of changes in soil health and productivity the following season as a result of issues like fallow syndrome. Several chemical and biological changes may occur during the duration of soil fallow. When soil is left naked for an extended period of time without any active root system or under saturated conditions, changes in soil biological characteristics might be carried over to the next season. Some of these potential alterations are caused by the lack of active root systems in these locations, which are necessary for the development of the microbial community that is responsible for nutrient cycling in the root zone.

As a result, using fallow to reduce plant residue inputs causes a decrease in soil OM, which starves soil microorganisms, limiting the metabolic capacity and biological activity of the soil. As a result, planting any annual crop during avoided planting can be extremely beneficial in maintaining the arbuscular mycorrhizae (AM) microbial community, which is critical for nutrient cycling such as P.

3. Monocropping

In a monoculture system, the lack of diversity destroys all of the benefits that nature offers to plants and soil. It means there are no plants that naturally offer nutrients to the soil, such as nitrogen-fixing legumes or ground cover crops that can be slashed and left to improve the topsoil's nutrient content. As a result, there are fewer types of microorganisms and bacteria on the soil since there are fewer nutrients available for them to survive on, and the soil's integrity is compromised because there are fewer plants with diverse root depths. Monocropping also eliminates ground cover crops, resulting in little natural protection for the soil from wind and rain erosion. Leaf litter mulch is not provided by any plants to replace the topsoil, which would be degraded anyhow. All of this contributes to the soil's constant degradation, which often means that it can no longer be used for agriculture.

4. Annual crops

Annual-based agricultural systems, on the other hand, typically experience much higher nutrient losses, owing to the removal of agricultural products from the landscape and frequent soil disturbances, as well as inefficiencies in internal nutrient cycling and poor synchronisation of nutrient availability with plant demand. In comparison to unfertilized and yearly harvested perennial lands, annual crop fields experienced significant loss of soil chemical and physical attributes. The amount of nitrogen in the soil under annual crops was much lower. Annual crops had lower levels of SOM, SOC, easily oxidizable carbon (ROC), and total soil nitrogen than perennial crops. As a result, the soil's moisture retention ability, microbial population, and microbial activity have all decreased. Because of the high exposition of the soil, soil erosion is a possibility. Long-term, the soil becomes less fertile and is unable to recover.

5. Use of inorganic fertilizer in excessive amounts

Because salt concentration is one of the most important qualities of inorganic fertilizers, they are likely to be harmful to agriculture in the long run, as salts are toxic to both plants and soil. The application of these inorganic chemical fertilizers on a regular basis depletes vital soil nutrients and minerals that occur naturally in fertile soil. Excessive use of inorganic fertilizers, contrary to popular opinion, does not assist replace soil nutrients and fertility, but just nitrogen, potassium, and phosphorus.

We also know that phosphorus does not dissolve in water and that too much of it might induce soil hardening. Similarly, alkaline fertilizers such as sodium nitrate increase alkalinity in the soil, diminishing fertility and rendering it barren. To put it another way, soil fertility and vegetation are heavily reliant on a steady supply of critical nutrients and minerals. As a result, over use of specific nutrients may induce an imbalance in the supply of soil nutrients, leading to soil deterioration and the loss of a stable soil's equilibrium. Leaching, pollution of water supplies, loss of microorganisms and beneficial insects, crop vulnerability to disease attack, acidification or alkalization of the soil, or decline in soil fertility can all result in irreversible damage to the overall system. They make things better. They hasten the decomposition of soil organic matter, resulting in soil structure degradation.

6. Excessive crop residue removal

Crop residue protects the soil surface by acting as a natural blanket. When crop residue is removed, soil exposition is increased, resulting in insolation, erosive rains, and blowing wind. The hydrological qualities of the soil decrease as the surface sealing is removed. Reduce the hydraulic conductivity of saturated and unsaturated water.

Reduce the rate of water infiltration while increasing the rate and amount of runoff. It causes a decrease in soil moisture and microbial content. After the protective mulch layer is removed, bare soils quickly lose moisture. Compaction of the soil also accelerates the decomposition and dispersion of soil particles. As a result, the soil's aggregate stability is compromised. One of the soil qualities most affected by crop residue removal is aggregate stability. It decreases with decrease in surface residue cover. Surface aggregates in soils without residue mulch are readily dispersed under the erosive forces of impacting raindrops. Accordingly the soil structure destroys with the excessive crop removal. Stability of aggregates is positively correlated with SOM concentration.

7. Fumigant with a Broad Spectrum (Pesticides)

Pesticides have the potential to travel off site, contaminating surface and groundwater and potentially harming aquatic ecosystems. They can be carried away from the soil by runoff and leaching, posing a threat to the population's drinking water supply. It also lowers soil quality by lowering the soil's ability to filter, buffer, breakdown, immobilise, and detoxify. Pesticide treatment of soil can lead to a drop in beneficial soil microbial populations. Pesticide misuse has consequences on soil organisms that are similar to antibiotic overuse in humans. Chemicals used indiscriminately may work for a few years, but there aren't enough beneficial soil organisms to hang onto the nutrients after that. Plants, for example, rely on soil microbes to convert atmospheric nitrogen into nitrates, which they can use. Triclopyr inhibits soil bacteria that convert ammonia to nitrite, which is disrupted by common landscape herbicides.

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8. **Herbicides with a broad spectrum of action**

The likelihood of environmental pollution from pesticides seeping into water bodies is influenced by how well the component is bonded to the soil. Some herbicides, such as glyphosate, have high sorption properties, which reduce the chance of leaching. As a result, glyphosate retention in soils and water bodies is high, and it has a negative impact on some soil species. Non-target creatures, such as amphibians, symbiotic mycorrhizal fungi, and earthworms, can be harmed by herbicides. They can diminish the earthworm's activity and reproduction. As a result, earthworms provide services such as shredding plant litter, mineralizing it and soil organic materials in their stomachs, and forming casts that improve soil nutrient availability and plant production. Their burrowing improves water infiltration and soil root penetration. Arbuscular mycorrhizal fungi (AMF) also assist plants get more water and minerals from the soil, improve drought tolerance, and resist infections. Glyphosate (and/or its metabolite AMPA) has been observed to diminish the viability of AMF spores and root colonisation, potentially reducing plant diversity.

Practices that improve soil health

A. **Conservation tillage or no-till**

Conservation tillage is a tillage strategy that reduces tillage intensity while retaining crop residue to conserve soil, water, and energy resources. It entails the planting, growth, and harvesting of crops with minimal soil disturbance. Reduced or no-till farming can result in a build-up of organic matter in the soil. Traditional plow-disk tillage operations severely deplete soil organic matter. Traditional tillage exposes enormous amounts of soil organic matter to oxidation by turning over the full plough depth. Smaller amounts of soil organic matter are exposed to oxidation with decreased tillage methods like no-till, strip-till or zone-till, resulting in greater organic matter in the soil profile over time. Reduced tillage can be difficult to implement, especially when new tillage instruments are required, and it can cost a lot of money.

Practices that improve soil health

Advantages of conservation or no tillage

1. Soil conservation - By leaving the soil untilled, you can prevent soil erosion. - When compared to tilled soil, runoff in no-till soils is reduced by more than half.

2. Water conservation - A key feature of the no-till method is better infiltration. The mulch layer and higher organic matter content promote soil moisture retention and reduce evaporation losses.

3. Soil fertility - In a 'no-till' system, soil organic matter levels are typically higher and bulk densities are lower than in a traditional tillage system - No-till systems conserve large amounts of nutrients and organic matter from erosion.

4. Soil temperatures - Under 'no-till,' soil temperatures and diurnal fluctuations are frequently seen to be lower.

5. Reduced compactness- In traditional tillage, soil compacts over time and roots in the deep layer of soil are unable to penetrate. Conservation tillage, on the other hand, can reach deeper layers of soil and penetrate root systems a good distribution. Conservation tillage does not compact soils, which is one of the reasons behind this. Another difference is that soil fertility in conservation tillage soil is higher than in conventional tillage soil. As a result, crop yields on conservation tillage soils are higher.

6. Weed control - The most difficult aspect of the no-till approach is weed control. In a no-till system, however, a holistic approach should be employed to control weeds. - Cover crops and increased planting density are two examples of how to do so.

7. Energy, time, and economy - Tillage, both mechanical and manual, consumes a lot of energy, while 'No-till' techniques have demonstrated to save a lot of energy. Farming with 'no-till' and conservation tillage has demonstrated to save a lot of time and energy compared to conventional tillage.

B. Mulching and cover cropping

Mulch is a layer of agricultural leftovers applied to the surface of the soil. In general, mulch is classified into two types: in situ and live mulch. The term "in situ mulch" refers to cover crop wastes that are utilised on the same area where they were grown. The live-mulch system is a crop production technology that involves planting food crops directly in a low-growing cover crop with minimal soil disturbance. disturbance. Its main benefit is that it smothers weeds and can play a vital role in soil conservation and fertility management. In the long run, cover crops can improve soil health and crop output. Between cash crops, cover crops are sown to prevent soil erosion and promote soil health and fertility.

Advantages of conservation or no tillage

1. Prevent soil erosion

When there isn't a primary crop available, cover crops can give protection. Plant leftovers lessen the effect of rains, which would otherwise dislodge soil particles and cause erosion. The cover slows surface runoff, allowing for better moisture uptake. Not only does the above-ground growth protect the soil, but the root system also helps to stabilise it by penetrating and holding the profile in place. By reducing fertiliser and pesticide runoff into surface water, cover crops and their decaying residues mitigate pollution.

2. Incorporate organic stuff into the soil

Cover crops in the rotation can help maintain or slightly increase soil organic matter, despite the fact that gains in soil organic matter take time. As organic matter and plant wastes decay, chemicals are produced that bind soil components into aggregates, improving structure and tilth. Greater soil permeability, aeration, water infiltration and holding capacity, cation exchange capacity, and ease of crop emergence and root growth are all benefits of aggregates.

3. Unused nutrients can be recycled or scavenged

Some cover crops are particularly good at recycling or scavenging surplus nutrients. Some nitrogen will be liberated and reused by future crops or used as protein in the feed when the cover crop dies or is removed as fodder.

4. Broaden the range of beneficial organisms

Increased plant residues and the tillage procedures commonly associated with cover crop systems may help certain beneficial species thrive in the soil. By rapidly decomposing organic debris and plant leftovers, animals such as earthworms, insects, and bacteria can enhance soil quality and boost nutrient availability. Earthworms, in particular, aid in the infiltration of water and the structure of the soil. Other insects drawn to the cover crop vegetation may bring benefits by feasting on pests that are hazardous to humans.

5. Weed control in part

Some weeds are suppressed by cover crops, which compete with them for light, moisture, nutrients, and space. By burying weeds, limiting weed seed germination and growth, and lowering soil temperatures, cover crops and their residues can operate as mulches or physical barriers. Weed development is chemically inhibited by allelopathic chemicals, which are emitted from living or decomposing plant tissue.

6. Nitrogen fixation in the atmosphere

Legumes have the potential to absorb and fix nitrogen from the atmosphere when they work together with particular bacteria. When high nitrogen legume residues are left in the field, they decompose, releasing nitrogen and other nutrients that can be utilised by future crops.

7. A potential feed source

Some cover crops, particularly grass species, can also be utilised as animal feed. These plants can be grazed or harvested mechanically as haylage or hay. Grazing, with correct management, can have a comparable impact because, even if the tops are harvested or grazed, the root mass and stubble remain to defend against erosion.

C. Crop diversification/crop rotation

Crop rotation is the practise of producing a variety of crops in the same location over the course of several seasons. Crop rotation can help to reduce the spread of soil-borne illnesses and improve soil health. Crop rotation refers to the order in which crops are planted on a farm. Changing crops of different families from season to season or year to year is usually a better farming strategy (Figure 14). Cereals (small grains) can, for example, be planted after legumes like alfalfa or beans since legumes fix nitrogen, which will assist the cereal crop after the legume residue has been worked into the soil. A rotation's design is unique to each farm and is influenced by a variety of elements such as soil type, equipment, water availability, and other factors.

Advantages of crop rotation

1. Many crops may have positive effects on succeeding crops in the rotation, leading to greater production overall.
2. Rotation are used to reduce pests and diseases in the cropping system and to control weeds by including smothering crop species (e.g. cowpeas) or green manure cover crops.
3. Improved soil quality (more or deeper roots; root exudates).
4. Better distribution of nutrients in the soil profile (deep-rooted crops bring up nutrients from below). 5. Increase biological activity.
5. Through rotations, peak labor times may be reduced and labour better distributed throughout the year if planting and harvest times are different.
6. Crop rotations may reduce the risk posed by extreme weather events like droughts or floods, as bad seasons or parts of seasons may damage some crops more than others.
7. Crop rotations can help balance residue production by alternating crops that create few and/or short-lived residues with crops that produce a lot of long-lasting residues.
8. Crop rotation minimises pesticide and herbicide usage, reduces pollution from off-site sources, and improves biodiversity. The goal is to enhance natural soil biodiversity while also creating a healthy soil microenvironment that is naturally aerated, better able to receive, hold, and supply plant-available water, better able to decompose and mitigate pollutants, and better able to receive, hold, and supply

plant-available water. Crop rotations and linkages can be beneficial to the environment.

D. Use of Organic Fertilizers

Organic amendments can aid in the increase of soil organic matter and, as a result, enhance soil quality. Manure, compost, and guano are just a few of the organic amendments available. The amount of nutrients that organic supplements may provide to the crop varies, therefore knowing the nutrient composition of the amendment material is critical. The amount of nutrients accessible from an organic amendment is determined by the material's original nutrient content, C:N ratio, soil mineralization rate (which is influenced by soil temperature and moisture), and soil nutrient levels (based on soil test). Sending the organic waste to a landfill is an excellent idea. Sending the organic material to a laboratory for examination to estimate the amount of amendment to apply to the soil to meet plant nutritional demands is a good idea. It's worth noting that applying huge amounts of compost with low nutrient concentrations might considerably raise the soluble salt content in the soil.

E. Integrated nutrient management (INM) –

INM is a holistic approach of integrated nutrient management by the application of balanced nutrients amalgamated through inorganic and organic sources needs to be considered as a key for managing soil health and its sustainability to reserve the trend of yield decline and fiscal losses. It will improve the soil health, sustainability and at the same time also enhance the input use efficiency and system's profitability (Tomar, 2016). INM is the maintenance/adjustment of soil fertility to an optimum level for crop productivity to obtain the maximum benefit from all possible sources of plant nutrients- organic as well as inorganic- in an integrated manner.

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