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WEED CONTROL IN IMPROVING CROP YIELD WITH TECHNOLOGICAL ADVANCEMENTS

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Abstract: **The need for agricultural production is directly associated with the increased global population and limited agricultural land resources. Natural dependencies on weather & climatic conditions and factors like weeds, diseases, pests, or combinatorial issues play a significant role in the final agricultural yield. While disease and pest controls are relatively straightforward, weed control has more challenges since it coexists with crops as a contender of the same soil nutrition and favorable environment during the plant growth period. Weeds are detrimental to harvest, but it is manageable to protect through various biological, chemical, cultural, or physical mechanisms and compliant with ecological methods. Literature reveals that the weed control methods have few shortcomings, influencing overall crop production. However, the advent of precision technology in agriculture will provide a way to overcome such drawbacks. This article highlights the literature, uses various technological methods to control weeds more precisely and considers other factors influencing weed management. The study also highlights a brief covering the need for management and development of technology involved in weed management, with more thrust on identifying a few more prevailing weed control challenges in India and provision for futuristic planning to support the small farmers as end-users!**

Key Words: **Variable Rate Technology (VRT), Weed Control, weed management.**

I. INTRODUCTION

In the early days, concerning population and availability of abundant agricultural land, the conventional crop growing system satisfactorily met society's needs. However, an exponential increase in population with time and the shrunk-cultivatable land area with urbanization led to hunger and famine as food grain growth per year was poorer than needed. Literature reveals that Indian agricultural development in the era 1950 – 60s was conventional and not backed by any improved processes, causing repeated uncertainty in agricultural growth. However, from the early sixties, with proper government initiatives and the effort of agricultural scientist Professor M. S. Swaminathanhad achieved a Green Revolution (GR) by producing high-yielding varieties of rice and wheat to increase food grain production. The G Rex tending from the mid-sixties to mid-seventies transformed India from a food-deficient country to a leading agricultural nation [70]. While the initial focus of GR was to expand farming areas, that required awareness and actions in the agriculture field led to the increased crop yields through the use of fertilizers, improved seed quality, chemical pesticides, etc.

Ever since the Green Revolution, India has continued its sustainability in crop production year-on-year rate and higher yield in agriculture and its associated sectors. In 2020-21, itcontributed20.19% Gross Value Product (GVP) (Fig.1) was a measure of whole economic output among three key economic sectors (services, industry, and agriculture)[1].

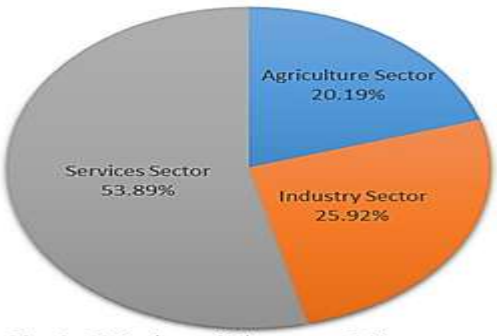

Fig. 1: GVA share (%) among 3 Keys Economic Sectors in India (2020-21)

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The agricultural GDP growth rate in India during 2015-16 to 2019-2020[2] is shown in Fig. 2.

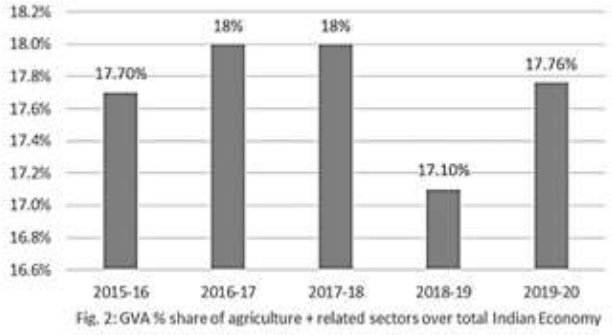

Fig. 2: GVA % share of agriculture + related sectors over total Indian Economy

Growth in this sector recorded fluctuating trends over the last few years. There can be many factors responsible for such a trend. One possible reason may be the inadequate soil responses to excessive or inappropriate use of chemical fertilizers [3].

In 2020-21, despite Covid 19, the agriculture sector in India exhibited a positive growth of 20.19% (Fig. 1). Such a variation in agriculture data needs more people's participation and contributions [72].

It is essential to mention that about 54.60% of the total population in India was directly or indirectly associated with agriculture as per the last census in 2011 [2], highlighting the significant involvement of this sector in the Indian socio-economic context. A fall in agricultural land (Fig. 2a) limits crop production due to fast urbanization. It hampers the harvest-growth rate to an alarming extent, coupled with weather & climate as natural dependencies and other factors like weeds, diseases, pests, rodents, or any of these combinations during the cultivation period [71].

Fig 2a: Year-wise Agricultural land (% of land area) - India
Source: https://data.worldbank.org/

The agricultural yield factor, such as the ratio of crop produced and associated cultivating land, is influenced by weeds as a competition to crop [67], being highly invasive and outcompeting. Tata Strategic Management Group 2014 reported a study [4] on more crop losses due to weed infiltration (34%) when compared with factors like insects (26%), diseases (26%), rodents (6%), and others (8%) (Fig.3) established a critical role of weeds.

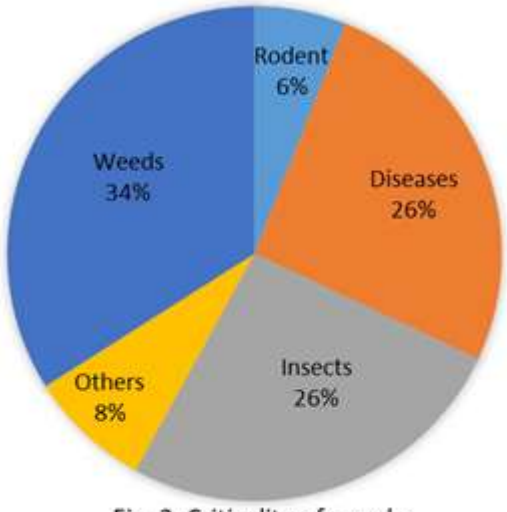

Fig. 3: Criticality of weeds

Information from this study plays a significant role in providing vital information and can be used to generate awareness among the farmers.
The present review article highlights the role of various parameters used for weed control practices improvised by experimental researchers and technological advancements across the globe to achieve higher agricultural yields.
The set policy target of the Government of India to double farmers' income is well in tune with the requirement of the current economic scenario.
The article also emphasizes the impact of technological advances in weed controls. However, these still have a few challenges of acceptance and deployment in developing countries to align as an affordable solution to farmers and cultural acceptance way forward [73].

Weed control practices and research in developing countries
Weeds usually grow from the previous season's seed, annual or can regrow perennial from dormant roots, underground stems, tubers, rhizomes, etc. Classification of weeds based on their lifecycle (annual or perennial), origin (indigenous or not), morphology (shoot or root) [74], habitat (terrestrial or aquatic), soil types (black soil, red soil, etc.),or association with a particular crop help to understand weed characteristics for its control, spread and separating from the crop. Weeds can further be identified as invasive weeds that can threaten biodiversity due to their allelopathic effect by producing biochemicals that influence the growth and germination of adjoining plants [75].
Conceptually weed management [34] prevents the growth or spread of weeds through cultural, physical, biological, and chemical methods. Fig. 4 depicts asituational and combinational hierarchy of these weed control methods.

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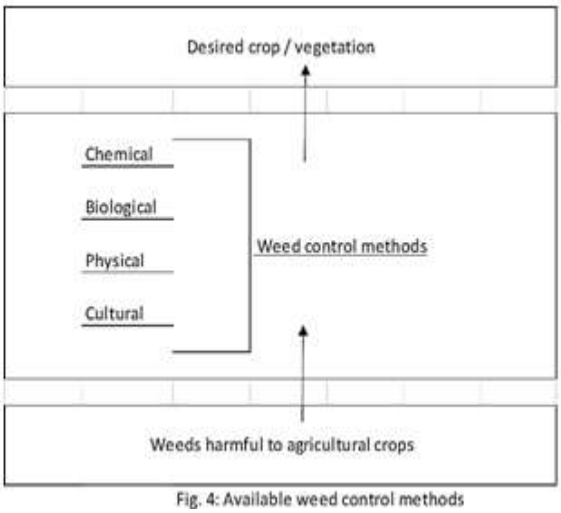

Fig. 4: Available weed control methods

For decades, herbicides have used chemical applications in weed control as a thriving traditional practice [5]. These are applied on the soil surface so that weeds germinating on the top or surface layers get killed due to the herbicide's incidental absorption. For perennial weeds, herbicides are injected as a sub-surface application into the lower soil layers at several points to reach the underground stems, tubers, dormant roots, and rhizomes that kill them [76].

Based on statistical analysis LD50 (Lethal Dose) model of toxicants [77], World Health Organization (WHO) classified insecticides and herbicides as extremely, highly, moderately, and slightly hazardous [6]. Higher toxicity is more detrimental to health and ecological systems [78].

Regulatory controls have been imposed from time to time to meet the sustainability of the environment [79].Using chemical applications to evolve weed resistance to multiple herbicides opened up studying the genetics of weed adaptation under the biological control of various gene inheritance [7].

Apart from herbicides as chemicals, foliar applications [80] provide fertilizer or chemical nutrients by spraying selectively on crop leaves, thereby depriving weeds of such nutrition [81].

Biological methods [8] deploy specific insects, pathogens, or animals acting as bio agents to invade weeds and prevent their growth or kill them. Traditionally, biological controls play a significant role in reducing weeds but not eradicating them. Physical methods apply physical forces to pull out and kill weeds through the human, animal, or mechanical tools. Such as hand-weeding, hand-hoeing, digging, burning, etc., are widely practiced depending on weed and crop situation during a cultivation period. Cultural practices help in creating favorable crop conditions. For example, regular cleaning and maintaining the sanity of crop area through tillage, irrigation, adding fertilizer or nutrients closer to plants, crop rotation, etc., are some of the popular cultural practices used in weed control. In addition, the removal of aquatic weeds is a preventive process applied to avoid water loss and insufficient water flows. It improves the physical & chemical characteristics of both water and hydro soil [9].

After sowing seeds, weeds start growing and competing with crops simultaneously. Thus Integrated Weed Management (IWM) is a situational approach [82] used to manage weeds infields by incorporating techniques or available methods as and when needed. It best uses the prevailing situation in a crop growing season. Chemical & biological prevention processes [83] are widely practiced in India through labor-intensive care. The use of technical gadgets can be an alternative to some of these methods.

Researchers, for better control of weeds and reduction in the use of herbicides/chemicals, experimented with different soil qualities. It is also observed that the physical weed control mechanisms such as precise inter and intra-row cultivation can reduce the use of chemicals.

Central Research Station, College of Agriculture in Bhubaneswar studied the performance and role of nutrients and microbial contents of soil on crop growth at the end of two consecutive seasons using combinations of different weed management and varying herbicide/chemical concentration. It improved soil quality through a microbial population of bacteria, fungus, actinomycetes, and dehydrogenase activities [8].

Anand Agricultural University (Gujarat) experimented on irrigated wheat using combinations of herbicide treatments during two successive rabi seasons. It yielded the required weed density and superior wheat grains due to the post-emergence application of combinatorial herbicides[10].Further, the analysis of two years of rice production data at the Agricultural Research Station, Ragolu (Andhra Pradesh), revealed a combination of green manure and need-based hand weeding yielded an increased benefit to cost ratio [11].

Tabuk University – Saudi Arabia conducted a study on the role of allelopathic compounds using natural herbicides on seed germination that resulted in higher weed control [12]. Such natural and eco-friendly approaches can supplement improved weed control by finding compounds that inhibit crop seeds and prevent unwanted weed germination.

Agronomy researchers at Kumarganj, Ayodhaya, used acombination of nitrogenous compounds as weed control treatments on turmeric. In two successive years, they recorded improved plant attributes like plant height, higher leaf area index (LAI), lower value of weed density, and dry mass [13].

Zonal Agriculture Research Station, Kalaburagi (Karnataka), studied the influence of weed management by allelopathy practices on nutrient status using plant extracts with a 50% reduction in herbicide. It suggests an increase in soil fertility and productivity over an extended period. The resultant outcome also indicates a more productive and sustainable growth [14].

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The experimental results on using pre-emergent herbicides suggested the killing of weeds before sprouting. It could act as an effective weed control method among all possible options, such as no weed control, manual weeding, and pre-emergent and post-emergent herbicide treatments [15].
A similar study on an irrigated blackgram at the College of Agricultural Technology, Kullapuram (Tamil Nadu), revealed the effects of pre-emergence (PE) and early post-emergence (EPoE) use of herbicides on weed management [16].
One of the studies experimented on a drill-cum-weedicide applicator developed in an indigenous tractor-operated seed sowing machine. Improvised mechanical tools used in herbicide applications reduced spraying time, material waste, and chemical exposure to farmers [17].
Understanding the dynamism in weed biology [84] is one of the important factors playing a significant role in developing and improving techniques, tools, and processes in managing agricultural yields. Furthermore, data and research results are essential to rolling back to the field for appropriate weed control mapping to climate (temperature, humidity, etc.) [85] and microbial soil conditions [40].

Use of herbicides in weed control

Herbicides are an essential part of agriculture due to their higher efficiency in weed control [39], improving crop production, and cost-effectiveness. Herbicides can be both inorganic and organic. Inorganic herbicides are synthetic, created in labs, while organic ones are made from natural chemicals. Organic herbicides have low toxicity, break down quickly and leave minimum residual effects, providing environmental benefits by being biocompatible [86]. High-potency herbicides that work in low doses are in demand to control broad-spectrum weeds [4].
Widespread use of herbicides exploited its efficiency in weed control resulting in soil quality deterioration [87] and leaving environmental impacts due to residual effects.
Recent progress of nanotechnology in the agricultural domain is ushering a new hope in herbicide usage through nano-herbicides for a sustainable and eco- friendly solution. It will supplement the end-users to control weeds using much lesser toxicity and chemicals, increasing manifold benefits [18].
Nearly 270 herbicides were added globally between 1936 and 2012 [4], as shown in Fig. 5.

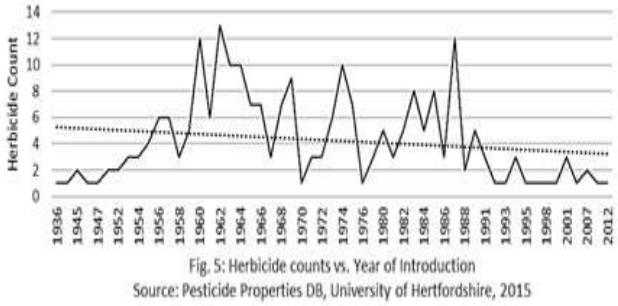

Fig. 5: Herbicide counts vs. Year of Introduction
Source: Pesticide Properties DB, University of Hertfordshire, 2015

Not many new chemicals were added post-nineties, indicating an overall downward trend with time. India imported herbicides way back in the 1960s, primarily for tea plantations [88].

However, herbicides drew the attention of farmers with the increase in labor costs for manual weed removal. Farmers switched to herbicides for higher efficiency and improved cost-effectiveness.

The consumption soon increased manifolds. Nearly 700 formulations of herbicides are available in the Indian market to cater to weed control [4].

In agriculture, insecticides, herbicides, bactericides, fungicides, and rodenticides are collectively called pesticides. Thus, the herbicides are a subset of pesticides.

Fig.6: Herbicide usage pattern in India during 1990 - 2010

The use of aggregated pesticides and herbicides in India shows (Fig. 6 and 7) a downtrend in consumption till 2008.Increased and ever-rising labor costs and labor scarcity added by technological intrusions accelerated higher consumption of herbicides.

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Fig. 7: Aggregated (1990 - 2010) Pesticide (total) use trend in India

It is reflected in the increased usage pattern in post-2008,substantiating projected herbicide consumption in India growing at a CAGR of 15% as planned till 2020[19].

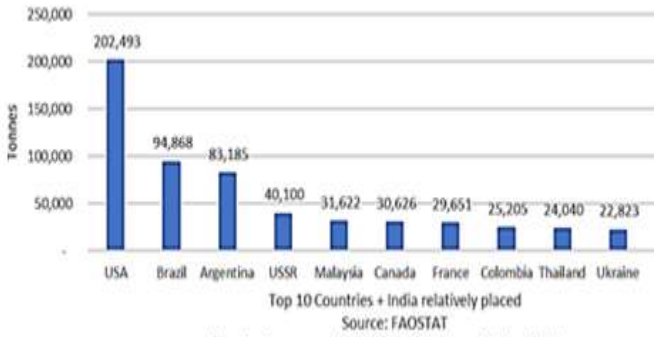

Fig. 8: Aggregated (1990 - 2010) top 10 herbicide

Aggregated herbicide usages from 1990 to 2010, shown in Fig. 8, have relative positions in the top 10 countries.

Table 1 (Source: FAOSTAT) captures the herbicides used in India from1990 to 2010.

	Table 1: Herbicides used in tones during 1990 - 2010 in India							
Year	Amides	Bipiridils	Dinitroanilines	Phenoxy hormone products	Triazines	Urea derivates	Other	Total
1990				791	275	1804	2951	5821
1991				686	285	1881	3151	6003
1992				750	277	2290	4120	7437
1993	1113			629	310	2307	2234	6593
1994	1919	46	95	612	472	2568	1098	6810
1995	2271	25	94	467	207	2490	566	6120
1996	2596	35	114	621	353	2657	882	7258
1997	2644	41	112	609	350	2674	562	6992
1998	2647	62	164	659	452	2662	835	7481
1999	2598	113	161	680	424	2685	819	7480
2003			213			2842	4445	7500
2004			115			2333	2706	5154
2005			289			1447	5223	6959
2006			82			2251	3971	6304
2007			98			1428	2596	4122
2008			81			1217	2276	3574
2009			49			1215	2956	4220
2010			71			1834	4430	6335
Total	15788	322	1738	6504	3405	38585	45821	112163

Table 2 (Source: FAOSTAT) has comparative data on top herbicides and pesticide-consuming countries with indicative percent use of herbicide/pesticides.

Country	Pesticides Use (tones)	Herbicides (tones)	(Herbicides / Pesticides) %
USA	407,052	202,493	49.7%
Brazil	166,048	94,868	57.1%
USSR	89,200	40,100	45.0%
France	87,806	29,651	33.8%
Colombia	54,770	25,205	46.0%
India	47,698	6,411	13.4%

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Figures 9 and 10 show India's harvested land and crop production from 1961 to 2019 for rice and wheat, respectively (Source: FAOSTAT). The growths are aligned with the onset of the green revolution, using fertilizers, pesticides, and herbicides to improve production yield. Usual monsoon rain, good soil moisture, and support from the government encourage farmers to favor growing rice and wheat as the main crop in India [20]. The data indicates near-linear growth with harvest area in Fig 9, 10. However, in recent years – particularly post-2015- rice and wheat production rates rose even higher despite a partial dip in harvest areas – primarily due to urbanization.

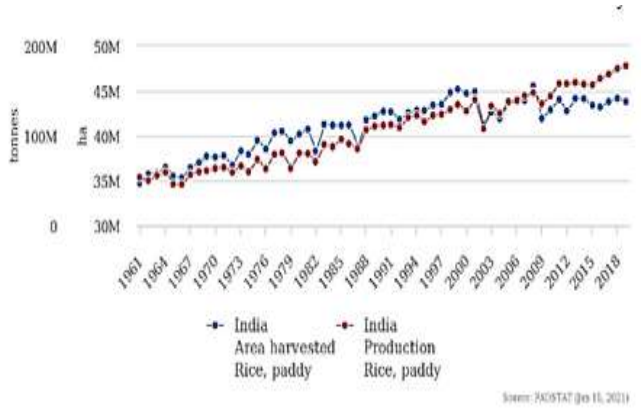

Fig. 9: Production / Yield quantities of Rice in India during 1961 to 2019

Figs 9 and 10 also substantiate consistent growth and high crop yields from the green revolution period for rice and wheat, respectively. Constant effort to educate farmers on the correct use of fertilizers, herbicides, application frequency, dosages, etc., resulted in aligning such growth rates [89]. However, reaching the farmers for such instances is not so easy. It is also challenging for the farmers to convey their needs effectively [19].

Technological advancements

Most small farmers usually pluck weeds manually from the field or spray herbicides using manual backpacks.

Their weed removal tools include brush cutter, trimmer, power weeders, etc. Backpacks prayers are vulnerable due to the lack of precision in the quantity needed and health concerns of persons involved in spraying. Existing practices have low yields without appropriate technology for precision usage. With an intent to increase the farmers' earnings, smart agriculture with intelligent technologies is essential to bring a difference. IoT-based innovative applications addeda revolution to the traditional weed control methods, supported by GPS-based remote-controlled robots with smart onboard sensors, Wi-Fi, and cameras [21]. Data from soil sensors, temperature &humidity sensors, air quality sensors, and sensors capturing video and photographs can be monitored near real-time and processed for decision making [90].

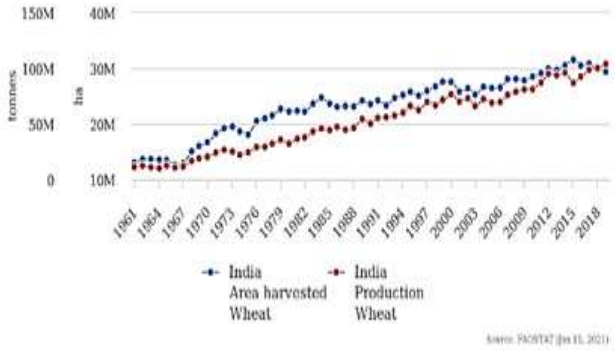

Fig. 10: Production / Yield quantities of Wheat in India during 1961 to 2019

Robotics in weed management is supported by computer vision and AI-triggered robotic actions precision in weed control using a programmable expert system to control and manage its activities [38] automatically. Variable Rate Technology (VRT) enables an automated decision-making robot to apply herbicides at variable rates without manually changing equipment. VRT enables Variable Rate Applications (VRA) of materials to a given landscape based on sensors, maps, and GPS data. The system can ensure environmental safety [22] by controlled use of herbicides.

Combined with electronics and mechanical engineering – mechatronic scan work as an autonomous machine for weed control in the field [43].Statistical tools and analysis of captured images by guided drones can help balance herbicide spray and weed removal by a trained robot with sensors mounted on it [23]. Herbicides control the weeding problem and increase crop growth [37].

Table 3: Source https://datacommons.org

Rank	Country	Population (2019)
1	People's Republic of China	1,396,530,000
2	India	1,254,020,000
3	United States of America	328,016,242
4	Indonesia	267,871,000
5	Pakistan	216,565,318
6	Brazil	208,495,000
7	Nigeria	200,963,599
8	Bangladesh	163,046,161
9	Russia	146,675,000
10	Japan	126,443,000

Robotics in weed control to hit precision targets need spatial localization [36] of weeds for precision application of herbicide spray in Site-Specific Weed Management (SSWM) using Unmanned Aerial Vehicles (UAV). It can monitor weeds and provide decision-supporting information

for precision spraying. Results demonstrated increased efficiency with competitive accuracy [24].

The development of proximal imaging systems with sensors closer to objects, when embedded in autonomous vehicles, can estimate plant morphology better above the ground dry matter biomass (BM) and leaf area index (LAI) at early growth stages [25].Satellite-based remote sensing detects and maps weed presence through broadband multispectral sensors like VNIR (Visible and Near Infrared) to derive Atmospheric Resistance Vegetation Index (ARVI) as fundamental variables [26].

Improvement in weed management over traditional methods, transformed with the advancement of IoT use of remote-controlled robotic vehicles, low power, and low-cost wireless sensors. Related notifications on smart phone applications engage farmers using Wi-Fi, 3G, 4G/LTE [27].Mobile phones are now an essential communication tool that empowers farmers with appropriate information in weed management [28]. Institutional roles are necessary for knowledge dissemination through such devices.

Table 4: Source https://datacommons.org

Country	Population Growth Rate (%) 2019
India	1.02%
United Kingdom	0.56%
Germany	0.27%
Canada	1.42%
People's Republic of China	0.36%
United States of America	0.47%

Challenges

India is estimated to have nearly 18% of the world's population [29]. In 2019, the population in India ranked second in the world next to China (Table 3). An increasing population (Table 4) and ever-increasing urbanizations require increased agricultural production as the focus of all farmers.

Weed control is an optimizing operational factor to enhance the yield. The challenge stretched further to emphasize food grain self-sufficiency and improve food security [33].

Applications of herbicides have inherent ecological challenges. Farmers at the grass-root level should be aware of such acts. Results of intrusive research in agriculture should be spread to farmers as best practices to cover the issues under discussion.

Combinatorial use of hybrid herbicides deployed using precision tools is some improvisations or extended practices to reduce the impacts of weed control on ecology. However, such technical fixes or improvements are yet to align and address the vulnerability of herbicide-resistant weeds, environmental impacts, and public health concerns. Dynamism in the simultaneous growth of weeds and crops continues to be a critical factor in agricultural yield loss. Scientific understanding of weed biology and related competition with crops for an integrated implementation approach may help higher yield resolution.

Many farmers use backpacks to spray herbicides for weed control [42].Such manual processes involve handhold sprayers and a manually operated compressed cylinder of liquid chemicals. This process induces uniform application of chemicals on visible weed areas with no scope to apply to specific coverage regions. A precision spraying-weeders for optimal herbicide use can reduce herbicide consumption by 80% and reduce cost. Such improvement will minimize environmental risk and supplement economic farming. It's important to share such information with the farmers as best agricultural practices and demonstrate improved mechanisms to achieve it.

For more extensive cultivating lands, robots in agriculture and robotic technology ease weed management. However, it has challenges related to crop types, the shape of the field, plant spacing, etc., that should consider before evaluating such options. For example, a robotic lawnmower (RLM) has a better working performance when compared with a riding mower (RM) and a walking mower (WM) in an orchard [30].

The challenge is to deploy efficient methodologies catering to site-specific weed control.

Precision tools with robotics and image processing in weed control are not available with easy affordability for sustainable solutions in many places, including India. Most farmers with smaller land areas depend on available cost-effective tools with low efficient conventional processes. Moreover, these tools do not address ecological and related harms, though they try to minimize them.

Industry involvement in device-advanced sensor technology in precision weed control at an affordable cost is a challenge. There will be hurdles in farmer awareness of such advanced devices' safe and convenient use. Thus, training is needed to use technology appropriately to improve crop growth rate. Predicting crop yield with weed factor will continue to be tricky, though wider acceptance and deployment of technical development can ease it further.

The way forward for futuristic scope

The use of modern technology in weed control helped save the crops and improve the overall production rate. The role of advanced technology in increasing production rate is recorded or observed. It reflects that using advanced instruments or devices for herbicide applications in agriculture may provide a good future scope in enhancing

crop production rates. Combinatorial use of herbicides using precision tools improves existing practices to reduce the impacts of weed control on ecology (resistance, ecology, health, etc.).Systems-level ecological thinking can help appropriate agronomical decisions to achieve sustainable weed management.

However, due to the steep increase in population, the agricultural production rate may not always match society's needs. As discussed, many risks and challenges are still associated with weed control. To over such challenges, researchers are working in multiple directions. Weed characteristics differentiating from crops are intensifying. Researchers can address the impacts of herbicide residues, herbicide-resistant weeds, the results of global climate change on crop-weed interaction, and environmental safety. With awareness of higher efficiency in weed control, herbicide consumption is rising. Dissemination of information to end-users to create awareness of ecological pressure is crucial. Impacts demonstrated to minimize herbicidal residues by local organizations through academic and research institutions collaborating with local administrations (panchayat, etc.) will directly connect to end-users (the farmers).

To balance technological advances and catering to the benefits through appropriate tool deployment among ordinary farmers. It's time to support entrepreneurial efforts in developing various applications and technical instruments for weed control using advanced wireless sensors targeted at small farmers and providing services to them. The approach may open a vista for new agricultural entrepreneurship in rural development.

These discussions suggest that a proper application of weed control technology can improve the required growth rate of agricultural production over time which will significantly enhance the level of society.

II. CONCLUSION

The present review article aims to discuss the literature covering various aspects of applications in technology in controlling weeds and enhancing crop growth. The article also covers various technological improvisations and applications in weed control.

Literature reports the harmful impacts of weeds on agricultural growth. It also highlighted the role of technology in overcoming the various challenges caused by weeds in the agro-economy and crop production. In view of this, the proposed review article discusses crop production and its salient features, constrained by natural factors (weather & climate) and factors like weeds, diseases, pests, rodents, etc.

The thrust of the review is to highlight the various parameters that influence the crop production cultivating land ratio. The agricultural yield factor measures the percentage of crop produced and associated enabling land area. While weather and climate are beyond human control, there is an utmost need to control weeds through improvisations in weed control processes and related applicable devices. A better grip over the issues requires a good understanding of weed characteristics in controlling the spread and separating it from the desired crop through appropriate processes. It can prevent weeds from growing or spreading through cultural, physical, biological, and chemical methods.

For decades, the chemical method has been the most successfully practiced using various herbicides among all the weed control practices. Such weed control approaches have a few shortcomings that need technological improvements to influence crop production with maximum green and salty land utilization as an agricultural field. Developments in precision technology and related alignment with agricultural applications aimat overcoming existing drawbacks and challenges of prevailing weed control methods.

Agricultural growth impacted by weeds, associated challenges, and futuristic scopes highlighted in this review suggests that technology plays a significant role in the agricultural growth rate to meet society's food security. It also allows a country to become self-sufficient in crop growth with available agricultural land.

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