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Review Article

PRECISION FARMING FOR SUSTAINABLE DEVELOPMENT OF AGRICULTURE IN INDIA

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Abstract: This paper applies method of systematic literature review through desk research. The paper focuses on how precision agriculture can be imparted in sustainable agriculture in India. The review identified that precision agriculture allows farmers to solve problems related to farming, can lead to higher productivity in farm, increases production by conserving natural resources, less environmental damage, reduced cost of production, efficiency of chemicals in crops, improves the quality of the produce, and maintains the environmental quality ultimately leading to a sustainable food system. It offers a path toward sustainable agriculture by providing innovative ways into a profitable, environment friendly and socially accepted agriculture. The major components of precision farming are; Geographical information system (GIS), Geographical positioning system (GPS), Satellite Remote sensing, VRT, UAVs, AI, IOT, SSCM, SSNM, Soil mapping, yield monitoring, data collection. It has the potential to create decent jobs for the youth, and attract youth toward agriculture. Small land holdings, high cost of technology, lack of technical expertise available locally, heterogeneity of cropping systems, data analysis and decision making, technological gaps seen in the farmers are the major constraint in the success of precision agriculture in India.

Keywords: *Precision, Agriculture, DRIS, GIS, GPS, NDVI, VRT, SCCM, SSNM*

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Introduction

Agricultural sector in India is very important to the Indian economy. The main source of livelihood of Indian population is agriculture. India is one of the major countries in the world in agriculture sector. Agriculture is currently the highest contributor to the GDP of India. In the next 20 years India's population is expected to become the world's largest, so the demand for food in India is growing day by day. This increase in the demand for food is essential to meet through higher agricultural productivity. Throughout the production cycle multiple challenges are there in agriculture sector. Adoption of innovative models can help India to become market driven and more efficient. Precision agriculture (PA) is the science of improving agricultural production and assisting management decisions by using new technologies and analysis tools. The word 'precision' means exactness or accuracy. The field is divided into various management zones based on nutritional status, soil pH, pest infestation, yield rates, and other factors which affects the production of crops. This is the new concept adopted throughout the world to ensure the effective management of fertilizers and irrigation processes to increase production, to reduce losses and to reduce the labor requirement.

Precision farming is a science based modern technology which provided management concept based on observation and response to intra-field variations [1]. In the long run the savings in cost of production are significantly higher than with traditional agricultural methods. Specific applications in precision farming brought increasingly more effective, technically-advanced solutions for improving farm yield and profitability. Same time it helps to save pesticides, herbicides, fertilizer, and other inputs used for farming. Feenstra, (2020) [2] stated that practitioners of sustainable agriculture seek to integrate three main objectives into their work: a healthy environment, economic profitability, and social and economic equity. Gyarmati *et al*., (2020) [3] reported that the major significant challenge of the precision agriculture is handling, storing, and processing of the data and connecting to the different devices. Through precision agriculture farmers can manage crop production inputs in an environmentally friendly way. Sharma and Ashoka, (2015) [4] reported that precision agriculture optimize production by using a key elements of information technology. It helps to increases the efficiency of chemicals in crops, improves the quality of the produce, increases production by conserving natural resources and maintains the environmental quality. There is a global competition for marketing of agricultural products, which is challenging economic viability of the traditional agricultural systems. So, it is essential to develop new and dynamic production systems [5].

Over the last decade, various technical methods have been developed to utilize modern technologies to respond to field variability. Such methods are known as geographic positioning system (GPS)-based agriculture, site-specific nutrient management, remote sensing, and precision agriculture. The major components of precision farming are; Geographical information system (GIS), Geographical positioning system (GPS), Satellite Remote sensing, Variable rate technology, UAVs, AI, IOT, SSCM, SSNM, Soil mapping, yield monitoring, data collection.

COVID-19 disrupted the agriculture and its supply chain. Agriculture sector is facing lots of challenges. This pandemic provided the opportunity to farmers and researchers to reconsider the approaches which currently they are using and to develop new farming system using environment friendly and greener technologies in farming. The objectives of this paper are to explore the new trends and new technologies in agriculture used in precision farming and to find out how precision agriculture can help for sustainable development of agriculture in India.

Material and Methods

This paper applies method of research to collect the information about existing knowledge about precision farming and which can be used for sustainable development of agriculture in India. The authors searched the articles related to precision agriculture, technologies used in precision farming and its use for sustainable agriculture development and challenges associated with precision farming. 184 articles were reviewed and after that screening of 42 relevant articles were done. After evaluating and selecting the most suitable articles and reports for review, the selected materials were analyzed and synthesized. Conclusions are drawn based on review of the selected articles and reports.

The Precision Agriculture Technologies

The various techniques are being collaborated with the advanced technology for use in agriculture. The precision farming technology can be divided into ground, aerial, and satellite technologies.

Technologies used in precision agriculture

Use of Global Positioning System (GPS) in Precision Agriculture

Ground-based technology permits farmers to gather real-time data of location. There are two modes of GPS performance; single receiver mode which collects the timing information, timing is processed into position; and differential GPS mode (DGPS) using two receivers of which one receiver is mounted in a stationary position and the other is on the machine [6]. GPS is suitable for the mapping of irrigation systems, fields, and roads, detection of areas with problem plants (Disease or pest infected plants), testing of soil in specific field areas. GPS in precision agriculture allows for controlling agricultural machinery and developed a parallel steering system for the tractor driving and variable rate application (VRA) for precise seed and fertilizer application in the farm.

Use of Geographic Information Systems (GIS) Technology in Precision Agriculture

GIS operate with object details and location data for creating detailed maps ex. for dividing the farm into separate zones, remote sensing is needed. These zones are divided on the basis of soil type, availability of nutrients, soil moisture content, pH and infestation of pests. All zones have their specific characteristics and the analysis of which requires use of GIS and GPS. GIS helps farmers to view records of soil survey maps and characteristics plant grown in the region. Aerial photographs and images provide additional information to farmers.

GIS helps for analyzing multiple farm management options by comparing and manipulating data layers. Ojo and Ilunga (2018) [7] reported that the GIS database can provides information about soil types, nutrient status, and quantity of chemicals, irrigation, surface and subsurface drainage, topography. It also establishes the relationship between elements that affect a crop on a particular farming. Rodrigo Ikaria, 2018 described a new Weighted Environmental Index (WEI) based on object-oriented models and GIS data and stated that WEI helps for better understanding of the socio-economic and environmental processes that induce land-use change.

Use of Variable Rate Technology (VRT) in Precision Agriculture

Farmers can use VRT technology to apply chemicals, fertilizer, seeds. to different parts of a field depending on their needs. Farmers can test their farm soil for different nutrients, such as nitrogen, phosphorous, potash. and they can apply fertilizers only those areas that lacks certain nutrients. There are different types of Variable Rate Technology, the map-based VRT and senor based VRT. Map based CRT helps to correct the number of applied fertilizers, pesticides, and other products based on the previously generated area map. Spati *et al*., (2021) [8] investigated that new sensing technologies, like drones or satellites make variable rate fertilization more attractive. Nitrogen application in variable-rate helps to reduce nitrogen losses without reducing yields.

The sensor-based VRT examines the soil with sensors in real-time and can help to the determine nitrogen deficiency. Then the control system estimates the required number of inputs. So, with the help of VRT, farmers can take care of plants more effectively, they can use additional resources if needed and there is no fertilizer run-off, fertilizers can be fully utilized by plants and it has positive impact on the environment. Chen *et al*., (2013) [9] reported that the inputs can be applied precisely in variable type and quantity in different part of the farm according to the present status and requirement. This is the practice of variable rate technology (VRT) in precision agriculture. The application of fertilizers at the right time, in right amount and at right location helps farmers to increase yield, save production costs and save environment by reducing the use of fertilizer inputs [10].

Chen *et al*., (2012) [11] & Shen *et al*., (2017) [12] reported that VRT is used in sprayers, in which programmable machines are attached with sprayers. These machines deliver the correct amount of chemicals depending up on crop condition, crop growth stage, and crop growth data of the previous crop. VRA technology is mainly used for fertigation but it can be used for application of herbicide, weedicide and in applying micronutrient as well as for disease detection in the crops [13].

Use of Unmanned Aerial Vehicles (UAVs) and Dusters in Precision Agriculture

UAVs are used in aerial technologies for crop management to monitor the yield's condition of the farm without scouting all fields in person. Crop dusters can be used for watering and sowing, farmers can attach a hyper spectral camera to any agricultural aircraft and they can record the needed information. The utilization of UAVs in precision farming has lately gained a lot of attention from the scientific community. Drones or UAVs are used in the precision agriculture; they are controlled remotely and consume less fuel. These drones can analyze the field thoroughly, conducting complex multispectral, thermal, and hyper spectral soil analysis. Use of UAV proved efficient tool for demarcating the exact regions in the farmer's fields suffering from disease, pest and other crop stress. This gives timely information to farmers so that farmers can take efficient measures in a timely manner to save the crop from economic failure [14]. Satellites and UAVs are used to to locate predatory insects and to sense the presence of insects and pests on farms. UAV s can quickly notify about this situation to farmers [15].

Use of Satellite Remote Sensing in Precision Agriculture

Satellite Remote sensing (RS) is the science through which information about objects or areas can be obtained from a distance from aircraft or satellites or sensors mounted on aircraft. Farmers can observe the yield health using satellite images of the crops grown in the field. Farmers get detailed information and the most accurate data about moisture stress, disease or pest infestation, structural anomalies, and nutrient levels. They can use satellite imagery for planning treatments of and selecting agricultural chemicals. It is most effective to combine scouting with satellite remote sensing through these growers can determine the cause of deviations from the normal condition of the crop. In this method labor cost and fuel is saved as compared to GPS and UAVs. Yin *et al*., (2019) [16] has divided the remote sensing system in to three broad categories *viz*., ground base system, spatial foundation system, and remote sensing data storage system. These systems include remote sensor, control and positioning system, carrier platform, data transmission and data pre-processing systems. Castro Gomez MG (2017) [17] classified the remote sensing system into two one is optical and another is SAR (Synthetic Aperture RADAR). Usually Landsat and SPOT satellite images have commonly been used for agricultural applications over large geographic areas. Kasana, (2022) [18] reported that remote sensing systems based on satellites are now introduced in India after gaining knowledge and experience from BHASKARA-I and II, experimental missions related to remote sensing satellites. With the help of the Indian Remote Sensing Satellite IRS-IA in 1988, IRS- IB I 1992, IRS-IC in 1995, and IRS- ID in 1997 these operational remote sensing systems are launched in India. Indian Space Research Organization (ISRO) and The Department of Space (DOS) are the nodal agencies responsible for the establishment of the Indian Remote Sensing System.

Yield Monitoring and Mapping in Precision Agriculture

GPS and satellite remote sensing are used for creating a field map when it is necessary to consider the environmental condition to obtain objective data, such as landscape, earth, and weather. Yield maps are the most important and valuable sources of the spatial data for precision agriculture. To avoid deducing conclusions that are affected by climatic factors like weather or other parameters a long yield history is essential of respective agro ecosystem in present scenario [19]. With the help of vegetation indices, farmers can effectively monitor the readiness of crops for harvest. Spatial variability of yield is very important in precision farming. With a yield monitor system installed on combine harvester, the yield data can be collected automatically while harvesting [20]. Most challenging tasks in agriculture are predicting yield of crop and it plays an essential role in decision making in farming. The predictions over multiple years are valuable for spatial patterns in yield. Soil, environmental, meteorological, and crop parameters are used to predict crop yield [21].

Micro Irrigation (Drip Irrigation)

The water should be given rightly to the root of the plant, and then it will be consumed only by the plant itself. The most efficient system that brings water right to the roots of the plants is the drip irrigation. Precision irrigation and fertigation helps farmers to use water precisely. Farmers can identify the areas with high or low soil moisture content and then a micro-irrigation system allows farmers to effectively plan the field's irrigation. With precision agriculture it is possible to carry out variable rate irrigation (VRI) for different parts of the field. Farmers can quickly identify areas of the field that needs additional watering, regions of flooding, or areas with excessive moisture. It helps to improve irrigation efficiency and ultimately results in water savings significantly. Drip irrigation is one of the waters saving technology used in precision farming and it is used for the potential usage of the available water [22]. In dry lands, drip irrigation is the most efficient water and nutrient delivery system. It helps to save water and ultimately save life. Along with saving water, drips irrigation has another advantage of having good irrigation efficiency [23].

Site-Specific Crop Management (SSCM)

SSCM is an agricultural management concept which is based on monitoring, counting, and reacting to crop variability between various fields or within one area. They are field data collection (such as pest incidence) and remote sensing data. Farmers can identify the problematic areas in the field with various possible pests, fungus, fertilizer misuse, weeds, lack of moisture. Then farmers can send a scout to make a report based on the data collected during the inspection. Hummel *et al.,* (1996) [24] reported that Site-specific crop management (SSCM) is used to improve farm's production efficiency by adjusting inputs (fertilizers and agrochemicals) given to the crop to varying local conditions within a field. Site-specific data on factors affecting crop growth and yields is obtained, which includes soil moisture status, weed pressure, nutrient status, landscape position, SOM content, and soil acidity by using sensors.

According to Mughal, (2021) [25] for site-specific crop management AI and IoT are the leading smart technologies. It was concluded that emerging smart technologies rely on smart data and specific frameworks are essential for collection of smart data and sharing it with other stakeholders of the agro value chain for improving food production and security. SSCM involves the use of automated seeders and chemical applicators to make spatially- variable applications to agricultural fields [26].

Site-specific nutrient management (SSNM)

SSNM is an approach of optimally supplying nutrients to crops to match their inherent spatial and temporal needs of the nutrients by using different SSNM tools such as GPS, GIS systems, VRT, remote sensing, yield monitoring. In this approach need based 'feeding' of nutrients is given to crop. Nutrients are supplied to the crop when they are really need it. SSNM relies on 5R's *i.e*., Right source, right dose, right time, right place and right method. The SSNM approach aims at increasing farmers' profit by achieving the goal of maximum economic produce of the crops. The nutrient diagnosis of crops is done with the help of chemical fertility analysis of soils, using the nutrient requirements of the studied species [27]. Most of the cultivated soils in India are acidic; there is high spatial variation in pH of the soil. We can detect nutrient stresses using remote sensing. We can do soil amendments by combining the data obtained in a GIS. This will help in site-specific applications of fertilizers in soil. This in turn would reduce nutrient losses and increase fertilizer use efficiency [28].

Rodriguez (2020) [29] reported that SSNM strategy provides guidelines for effective N, P, K. management and it helps farmers to make better decisions on fertilizer application rice production. Soil organic matter also significantly affects the nitrogen fertilizer uptake so SSNM strategy can be made to be more adaptive to farmer's fields, if these relationships are accounted for in the fertilizer recommendation algorithm. Sarkar *et al*., (2017) [30] suggested that it is essential to develop dissemination mechanisms that consolidate the complex and knowledge-intensive SSNM information into simple delivery system. So that farmers can rapidly implement it for maintaining soil health and ensuring future generation food security.

Soil Mapping in Precision Agriculture

Quality soil mapping is very important in precision agriculture, with its help; farmers can evaluate the chemical composition of soil, soil properties, the presence of nutrients'. Soil mapping practice is existed for a long time, but with the help of modern technologies we can obtain more detailed information and we can make the new generation of digital maps more efficient. For obtaining data, farmers can use several types of precision agriculture sensors. Electrical characteristics of soils, such as the presence of potassium can be analyzed by electrochemical sensors. Based on coefficient of reflection of light from the ground Optical sensors interpret data based. Mechanical sensors in contact with the soil determine the types and density of the elements contained in it. SSNM is an approach of supplying plants with nutrients to optimally match their inherent spatial and temporal needs for supplemental nutrients by using different tools of SSNM such as remote sensing, GPS, GIS systems, VRT, yield monitoring.

IOT in Precision Agriculture

IOT based precision agriculture, helps farmers to control all the most critical information: from air temperature to soil conditions. IOT platform gives farmers sufficient control over the field with data sensors and remote control. With this technology farmers can solve the problem of researching the large farms manually. Now robotic systems are also used, which take on the part of a person's work. Use of Innovative irrigation technologies helps to reduce manpower requirement and ultimately reduce human labor requirement. It helps to use water more rationally. Akhtar and Sofi, (2022) [31] conducted a local survey to know about views of people regarding precision agriculture and they found that many challenges are there for implementing the IOT data analytics and machine learning at large scale. These challenges include cost of implementation, training, deployment, weather conditions and other parameters. If these limitations are overwhelmed then we will get profits. Precision is stand on four factors appropriate source, appropriate time, appropriate quantity, and appropriate place.

Murugamani, (2022) [32] suggested a system which uses a regression technique of artificial intelligence for identification and classification of leaf diseases. After identification of infection the information is delivered to the farmers through the android app. The Android app provides information about soil parameter values like moisture, humidity, temperature and Chemical level. IoT can helps to provide tailored solutions for specific farm requirements. It also allows for the optimal use of water along with the minimal use of chemicals on the crop. We can predict well in advance the natural disasters affecting the field and we can take precautionary measures well in advance to protect the crop in the farm from damage [33].

Artificial Intelligence and Machine Learning

Artificial Intelligence (AI) and machine learning (ML) are the new intelligent tools for managing agricultural production and precision agriculture is improved with use of these tools. Both tools provide Image-based pattern recognition systems which can be used for adjustment of the nutrition and watering of plants according to their type. Artificial intelligence can easily recognize specific types of weeds. Sprayers are equipped with AI and so these sprayers spray chemicals on specific types of weeds only, without affecting the other crops. Machine learning and AI can help to reduce on-farm field waste by increasing crop quality. AI is mostly used in development of farm robotic applications, such as robotic harvesters or robotic weeding machines. Dakir *et al*., (2021) [34] reported that precision agriculture has benefited from the development of emerging technologies like Internet of Things (IoT), big data, and artificial intelligence (AI). Lodh and Galghat (2018) [35] suggested strategies to construct precision agriculture in India. AI precision agriculture technologies are regarded as three parts: the fundamentals, the engineering, and the supporting. Innovative AI technologies can significantly contribute to organize, connect, and further develop this knowledge to better supply the collective demand for food. Talaviya, (2020) [36] reported that the precision weeding techniques overcomes the large amount of crops being lost during the weeding process. Autonomous robots improve efficiency of weeding at the same time they also reduce the need for unnecessary pesticides and herbicides. With the help of drones farmers can spray pesticides and herbicides effectively in their farms, and they can also do plant monitoring effectively.

Important obstacle is the exorbitant cost of different cognitive solutions available in the market for precision farming. It is essential to make the technology more affordable so that the technology can reaches to the masses.

Sharma *et al.,* (2021) [37] reported that key components of the next agriculture revolution are Machine Learning together with Internet of Things enabled farm machinery. Intelligent irrigation which includes drip irrigation and intelligent harvesting techniques are help to largely reduces human labor. Knowledge based agriculture can improve the sustainable productivity of the farms and quality of the farm products.

Data Collection and Analytics

Data generated during all farm actions is collected and then analyzed to get deeper insights which can help farmers for taking decisions for smart management of farm. This helps for better use of different farm resources which enables to use sustainable practices and saving time and money. Bharath and Anala, (2017) [38] reported the promising solution for numerous problems faced during crop production such as disease prevention and control. According to them the development and use of M2M remote telemetry as an entailment of Big Data processing on Cloud infrastructure which could be a promising solution. Sourav and Emanuel, (2020) [39] reviewed the recent trends of Big Data technology in the field of precision agriculture and reported that Big Data application areas in the agricultural sector are continuously emerging and in near future these growing technologies will play a lead role in agricultural development.

The rapidly expanding application areas and noticeable contributions indicate that the future dependency of Big Data in the agricultural sector will increase. Chengui and Kechadi (2022) [40] did the systematic review of the potential use of the data mining process in crop production and management and highlighted the serious gaps which can be considered in future studies. The majority of the current practices were dominated by statistical analyses and small machine learning systems. Digital agriculture will provide new insights into how farmers can grow crops more efficiently and how they can minimize the impact on the environment. It also promises new levels of scientific discovery and innovative solutions to more complex problems.

Benefits of Precision Agriculture

Better sustainability and less impact on environment are the two important benefits of precision agriculture. The main goal of sustainable agriculture is to meet the current needs of society for food, without affecting the environment. Precision agriculture help to conserves the natural resources by allowing farmers to cultivate various crops and soil with maximum efficiency.

Farmers can take precise decisions and manage use of farm inputs and nutrients more carefully, which ultimately results in less wastage of fertilizers and nutrients due to runoff. Farmers can use remote sensing to know exactly where disease and pests incidences are high in the field and then they can apply chemicals only where they are needed instead of spraying on entire field, which helps to reduce quantity of insecticides and fungicides used by farmers. It helps to maintain soil health by reducing the quantity of pesticides used for farming. It helps to minimize the cost of materials and resources (ex. water, seeds, fuel). In the long run the savings are significantly higher in precision than with traditional agricultural methods Farm managers can hone in and reduce fuel consumption by monitoring equipment and drivers, which results in fewer emissions. It also helps to lower down the dependence of agriculture production on weather conditions.

The review on smart farming done by Musa *et al*., (2020) [41] and they identified that smart farming can lead to higher productivity, less environmental damage, lower production cost, and it has the potential to create decent jobs for the youth, ultimately leading to a sustainable food system.

Challenges of Precision Agriculture

Even though precision agriculture is having significant benefits, it has several challenges also. It is necessary to carefully analyze economic viability of the precision agriculture. Precision agriculture does not guarantee increase in income from farm because agriculture is dependent on the weather condition. Ready-made farm management solutions are essential for farmers but most of the technologies in precision agriculture provide soil and plant data only. We can apply computer technology in agriculture management but with its application in precision agriculture, cyber security becomes more critical. Cyber attackers can steal data and even resources of the user. But this system is effective and promising because its advantages are more as compared to the disadvantages.

Campbell, *et al.,* (2014) [42] reported that many current farming practices damage the environment and are a major source (19–29%) of anthropogenic greenhouse gas (GHG) emissions such as carbon dioxide and nitrogen dioxide. Small land holdings, high cost of technology, lack of technical expertise available locally, heterogeneity of cropping systems, data analysis and decision making, technological gaps seen in the farmers are the major constraint in the success of precision agriculture in India. Bharath and Anala, (2017) reported the promising solution for numerous problems faced during crop production such as disease prevention and control. According to them the development and use of M2M remote telemetry as an entailment of Big Data processing on Cloud infrastructure which could be a promising solution. Precision farming includes buying new technology enabled equipment which can be an additional expense on a farm budget. Precision agriculture is not successful in India because of lack of awareness among the Indian farmers, about when and how to use PA in the fields [43, 44].

Conclusion

COVID-19 disrupted the supply chain in agriculture which further challenged the agriculture sector in India. Farmers can tackle this issue through precision agriculture or smart farming; it can tackle food supply chain. Precision agriculture has overall potential to help alleviate the problems those the future agriculture is going to face. Precision agriculture allows farmers to solve problems related to farming. It offers a path toward sustainable agriculture by providing innovative ways into a profitable, environment friendly and socially accepted agriculture. The various techniques are being collaborated with the advanced technology for use in agriculture. The major components of precision farming are; Geographical information system (GIS), Geographical positioning system (GPS), Satellite Remote sensing, Variable rate technology, UAVs, AI, IOT, SSCM, SSNM, Soil mapping, yield monitoring, data collection.

Better sustainability and less impact on environment are the two important benefits of precision agriculture. Precision agriculture will protect the environment, boost the farmers' income can attract more youth into the agriculture sector. Precision agriculture provides the ability to the farmers to use crop inputs (irrigation water, fertilizers, pesticides) more efficiently. The developments are going rapidly for mapping infestations of insect, pest and disease *via* GPS and GIS receivers. Location-specific practices can be adopted considering the spatial variability of land to minimize the cost of inputs, maximize crop production with the minimal damage to the available resources like soil, water, environment. and human health. Even though precision agriculture is having significant benefits, it has several challenges also. It has been noted that there are challenges in developing precision agriculture in India and it will take time but farmers will adopt this new concept which will help to increase income of Indian farmers through increase in farm yield along with saving environment. It is necessary to carefully analyze economic viability of the precision agriculture.

Application of research: Indian farmers are searching for new technologies for sustainable agriculture for meeting the current needs of society for food, without harming the environment. Precision agriculture is helpful for both farmers and the environment. In this review paper we have reported the most advanced technologies which can be applied in farms and that allows solving the problems related to farm production and save environment and to support the decisions associated to the production of crops.

Research Category: Sustainable Development

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