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Site specific nutrient management: An overview

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Abstract
The optimisation of agricultural practises is required to achieve both high yields and environmental sustainability in response to the growing worldwide need for food production. In order to accomplish these two objectives, site specific nutrient management (SSNM) has emerged as a promising strategy. 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. With the invention of SSNM, it has become possible to manage soil nutrient variations throughout a field with prescription fertilizer applications. Stress management is another area where SSNM can help Indian farmers. Most cultivated soils in India are acidic, whereas spatial variation in pH is high. Detecting nutrient stresses using remote sensing and combining data in a GIS can help in site-specific applications of fertilizers and soil amendments. From an economic perspective, SSNM holds the promise of cost savings through judicious use of fertilizers, making agriculture more financially viable for farmers. Effective coordination among the public and private sectors and growers is, therefore, essential for implementing new strategies to achieve fruitful success. So site-specific nutrient management is a game changer in modern agriculture, combining localised accuracy with sustainable practises. As the world's population continues to grow, embracing SSNM could provide a viable way to maintain food security while minimising environmental consequences. To realise the full potential of SSNM, however, a consistent commitment to research, technological integration, and information sharing is required.

Keywords: Site specific, soil fertility, GPS, modern agriculture, sustainability

1. Introduction

The world's most significant use of land is for agriculture. From the total 14 billion hectares land area worldwide, 3 billion hectares is certainly available for cultivation, with only 1/2 is actually being cultivated at various production levels due to various restrictions (Yadav and Sarkar 2009) [80]. Our world's sustainability is fundamentally dependent on various nutrients. To satisfy the feed of 7 billion people, mankind has doubled or more than double global land based nutrient cycling. Most of Africa as well as sections of South America and Asia, have a population battling food insecurity and malnutrition in the twenty-first century. Inadequate use of mineral-fertilizers, particularly the misuse of nitrogen and phosphorous, is causing freshwater contamination, acidification and eutrophication of coastal and terrestrial ecosystems, and a decrease in bio-diversity against continuous climatic changes. The upcoming generation of the world will face problems with available land per capita, freshwater supply will also decrease to a scarcity level in various countries, & extreme forms of degradation will affect about 300 million ha of productive land, mostly in countries where farmers as well as governments cannot invest in restoration of soil (Nieder 2006) [40].

The Green Revolution occurred in 1960 assured food security for the developing world by introducing novel agricultural inputs, primarily high-quality seed and improved production systems. However, the reasons responsible for post-green revolution concerns are unmethodical exploitation of natural resources with no consideration for their carrying capability and injudicious use of agricultural chemicals. In the meantime, the deterioration of land and water quality, loosing biodiversity of flora and fauna, change in pattern to utilize the agricultural land towards urbanization & industrialization, degradation of environment which resulting in climate change are important issues of post-green revolution that threatening the global sustainable food security (Paroda 2003) [45].

World will need to increase production and improve quality from less land in order to feed the rising population. A proper balance of nutrient levels is the crucial component to fulfill all the purposes of sustainable cultivation (more food & fiber, profitability, input use effectiveness, & an acceptable regard for the environment). The management of crops in India has been influenced by the increased usage of external inputs during the last four decades. A significant impact in increasing crop productivity has been played by fertilizers. Production of food grain reached over doubled from roughly 98 MT in 1969-2000 to a record of 212 MT in 2001-2002, whereas use of fertilizer reached nearly 12 times, from 1.95 million tons to over 23 million tons in 2007-2008 (Rao, 2009) [53]. Without having the opportunity to increase the area of cultivable land beyond 142 million hectares, most of the desired increasement in food grain production must be managed through yield increasement per unit area, particularly for most important staple food crops such as rice, maize, & wheat, which have responded significantly to the beginning of green revolution technologies, accounting for more than 80 percent of total production of food grain (Johnston *et al*. 2009) [59].

The global use of different fertilizers had done a tremendous impact to increasing food production. Scientists estimated that nutrients inputs are account for 30 percent to 50 percent crop production. However, poor nutrient use efficiency as well as accompanying pollution of environment and the global warming issue, have generated severe concerns about current nutrient management application (Doberman *et al*. 2002) [14]. The application of fertilizer recommendations are frequently based on averaged data of crop response across vast areas, despite the fact that farmer's fields vary greatly in terms of nutrient supplying capability and crop responses to nutrients. Though, blanket application of fertilizer recommendation lead farmers to over fertilize in certain areas while under fertilizing in others, or applied an incorrect nutrient balance to their crop or soil. Site Specific Nutrient Management serves as an alternative of blanket guidance, its goal is to optimize the nutrient supply of soil over space & time for matching the crop necessities.

Site Specific Nutrient Management (SSNM) is a method of providing nutrients to plants that best matches their natural spatial and temporal demands for additional nutrients. The SSNM provide a method for 'feeding' crops with nutrient based on their nutritional needs. The SSNM strategy seeks to increase farmer profits by obtaining maximum economic yield (Tiwari 2007) [72]. It enables farmers to drastically alter fertilizer usage to cover the gap between a high-yielding crop's nutritional demands and the nitrogen supply of the crop from naturally occurring indigenous sources like soil, crop leftovers, manures and irrigation water. The SSNM technique tries to apply nutrients at appropriate rates and timings in order to produce high yield crop and nutrient use efficiency. It has no stated goal of either reducing or increasing fertilizer consumption (Buresh *et al*. 2005) [6]. It is one of the potential ways to enhance soil and environmental health to double the farmers' income and fostering self-reliance in India (Sarkar *et al*. 2017) [57], maintain increased agricultural production and food security for nation. Thought its potential for eco-friendly sustainable agricultural production, Site Specific Nutrient Management (SSNM) can be one of the strategies to relieve all kinds of hunger and malnutrition (Stewart 2002) [67] but the efficiency of fertilizer nutrient recovery is very poor, ranging from 20-40% for N, 15-20% for P, and 40-50% for K, and 5-12% for secondary and micronutrients (Rao 2014) [54].

Poor soil health, widespread multi nutrient deficits, and unbalanced nutrient usage are the reasons for poor nutrient use efficiency in India, according to the FAI. Traditional guidelines for nutrient handling been developed by state and central association together for nearly every cultivable crop in India. However, blanket recommendations of fertilizer have limits due to unpredictability of intrinsic soil fertility and other edaphic variables (Ladha *et al*. 2003) [34].

Recent advancements in the IT sector, in addition with electronics and computer science, communication, and space technology, have had a favorable influence on agricultural technology development and distribution. SSNM technologies are used for crop fertilization in precision agriculture. A few ways for SSNM practices include lab testing and field based practices, map & proximal sensing based fertilizer suggestion, yield mapping and monitoring, and Variable Rate Application equipment. The appropriate Farm Management Information System was created and used for VRA of farm agri-inputs in accordance with built-in Decision Support Systems (DSS) and prediction models from various data sources (Adhikari *et al*. 2011) [1].

2. Importance of SSNM in present scenario

Two critical SSNM strategies are map-based and sensor-based procedures. The broad and core aspects of site-specific management technology include site information, current available technology, and efficient management. The map-based SSNM approaches include three main steps: assessing soil & crop variability, controlling variability, and evaluating variability (Verma *et al*. 2020) [75]. Based on the variability map and the management zone, site-specific fertilization was advised (Gorai *et al*. 2017; Miao *et al*. 2018; Vasu *et al*. 2020) [20, 39, 74]. The sensor system monitors the necessary soil qualities or crop characteristics; the measured data is then utilized to calculate fertilizer using a specific algorithm, and the results are used to control the variable rate applicator (Gupta *et al*. 2006; Larson *et al*. 2020) [23, 35]. N fertilizer management with proximal sensors has been widely researched and practiced in different crops (Prakash *et al*. 2018; Padilla *et al*. 2018; Singh & Ali 2020) [51, 44, 3]. Remote sensing systems based on thermal and spectral techniques have the ability to organize nitrogen fertilization across broad regions by rapidly identifying nitrogen status in the canopy (Yousfi *et al*., 2019) [81]. Green Normalized Difference Vegetation Index and Soil Brightness estimates from remotely detected images, combined with soil organic carbon & nitrogen datasets, were used to create a site-specific management zone. Furthermore, DSS provides users with rapid and smart farm management decisions; mobile applications and web services accelerate the diffusion of SSNM technology to farming societies (Cammarano *et al*. 2020) [8].

a) Improve productivity, farm livelihood, food security

In general, SSNM preserves or enhance agricultural yields. In a 2014 study of 13 Southeast Asian locations, SSNM increased grain yields by 13% over a 3-year period; however yields fell somewhat in the first year (Pasuquin *et al*. 2014) [46]. A study of 179 rice fields in six Asian nations showed that SSNM increased yields by 7% and average profitability by 12% (Dobermann *et al*. 2002) [14]. In comparison to farmers' typical fertilizing techniques, SSNM increased wheat grain production by 18-27% in recent tests over a significant number of sites in wheat farming systems throughout South Asia (Jat & Satyanarayana 2013) [28]. An average of 107 on-farm studies in Chinese rice fields indicated that SSNM produced 5% greater grain yields than farmers' practices, owing to reduced pest and disease damage induced by optimum N inputs (Peng *et al*. 2010) [49]. It can increase the total profitability of agro-companies by conserving farmers' fertilizer cost; however it depends on basic yields, basic fertilizer consumption, and fertilizer cost. SSNM tests were conducted on about 14,000 hectares of wheat and barley crops in America. It did not affect on crop yield and saved 40-75 kg N/ha (Ortiz-Monasterio and Raun 2007) [43]. SSNM enhanced the net return from $ 390 to 1071/ha in wheat production tests in India, while increasing labour expenses by $ 123/ha (Singh *et al*. 2015) [63].

b) Aid in adapting climate change impacts

The majority of SSNM research focuses on boosting production and revenue, as well as mitigation. However, proper fertilizer management in overall should boost crop yields and resilience. Furthermore, if fertilizer inputs are optimized based on attainable production in the present year, farmers may save price on fertilizer in years with adverse weather (Thornton and Herrero 2014) [71].

c) Mitigate greenhouse gas emission

As a greenhouse gases mitigation approach, SSNM is best relevant to farming systems that currently utilize, and notably abuse, N fertilizers. SSNM decreases the amount of nitrogen which is applied, lowering entire reactive Nitrogen (Nr: ammonia, ammonium, nitrate, nitrite, nitric oxide, nitrous oxide) wasted into the surrounding atmosphere (for example, by volatilization / leaching) and the release of N_2O. Adoption of SSNM procedures led in a 30 percent reduction in the usage of fertilizer in rice in one study (Wang *et al*. 2007) [76]. In another wheat research, releases of nitrous oxide were decreased by 50 percent (Matson *et al*. 1998) [38] while losses from leaching were decreased by 90 percent (Riley *et al*. 2001) [56]. Slow-release fertilisers too result in fewer nitrous oxide releases because nutritional demand of plant and fertiliser application are better synchronised. Fertiliser deep insertion is another promising approach, with reactive nitrogen losses reduced by up to 35 percent. Using slow-release goods and processes as part of SSNM can reduce the release of nitrous oxide and reactive nitrogen losses to the environment due to leaching and volatilization (Gaihre *et al*. 2015) [18].

Where soils are nutrient-depleted, SSNM may recommend additional N application, although this does not always result in increased emissions (Dobermann *et al*. 2002) [14]. According to a developing body of research, the emission feedback to increased nitrogen intake, if exponential instead of linear, with extremely low releases until plant demands are fulfilled (Shcherbak *et al*. 2014) [60].

3. Current status of nutrient imbalance in soil

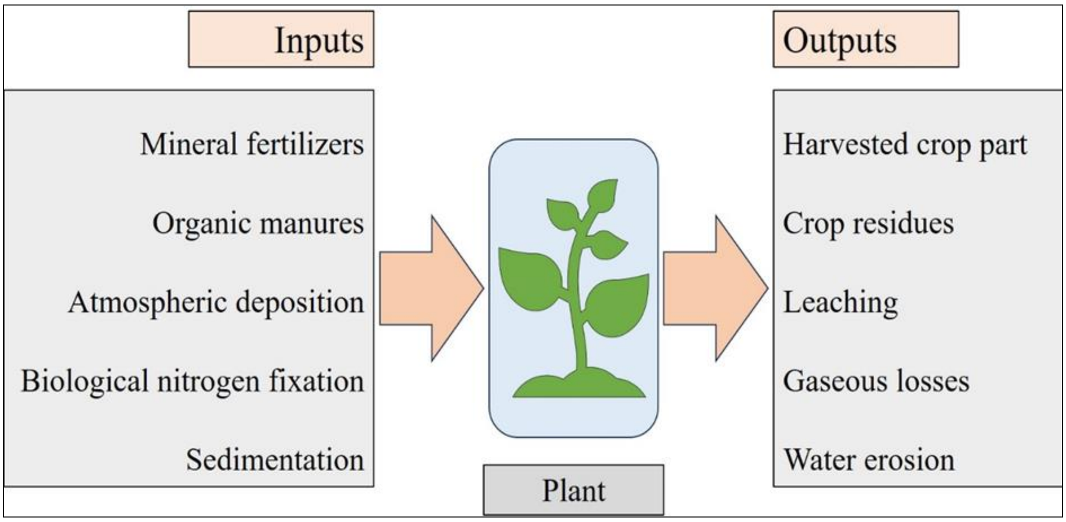

Fig 1: Nutrient input and output sources

a) Production and consumption scenario

India is currently the world's third-largest producer of fertilizers (after China and the USA) and second-largest user (behind China). It ranks second in N and P_2O_5 intake and fourth in K_2O intake in terms of nutrients. In India, urea is the fertilizer that is most produced (86%), used (74%), and imported (52%) (FAI 2018) [15].

N production increased just 0.4% over 2016-17, reaching 13.43 MMT in 2017–18. During the time period, the output of P at 4.73 MMT increased by 3.8%. Even though urea output somewhat decreased, there was a considerable increase in the production of DAP and NP/NPK complex fertilizers, which resulted in an overall rise in fertilizer production in terms of both products and nutrients. The overall production of urea, DAP, NP/NPKs, and SSP in absolute terms during 2017–18 was on the order of 24.03 MMT, 4.65 MMT, 8.26 MMT, and 3.90 MMT, respectively. Urea and MOP imports rose in 2017–18, while DAP and NP/NPK imports fell from the previous year. Urea and MOP imports rose by 9% and 27%, respectively, during that time. On the other hand, compared to 2016-17, imports of DAP and NP/NPKs decreased by 3.8% and 4.4%, respectively. Urea, DAP, NP/NPKs, and MOP each had a quantum import of 5.98 MMT, 4.22 MMT, 0.50 MMT, and 4.74 MMT, respectively, in 2017–18 (FAI 2018) [15].

In terms of nutrients (N, P, and K), the annual fertilizer use has climbed from 0.07 million MT in 1951–1952 to more than 25.95 million MT in 2016–17, and the consumption per hectare has risen from less than 1 Kg to the level of 130.8 Kg. P_2O_5 and K_2O constituted only 26% and 8% of the overall N: P_2O_5: K_2O intake in India in the years 2012–2013, respectively (Majumdar *et al*., 2014) [37]. The ratio of all-India NPK utilization increased from 6.7:3.1:1 in 2011–12 to 8.2:3.2:2.1 in 2012–12 and 8:2.7:1 in 2013–14 (Desai *et al*. 2017) [13].

b) Imbalanced fertilization

The popular saying that should be envisioned is "The nation that destroys its soil destroys itself."-Franklin D. Roosevelt. India has a significant issue with the inappropriate use of several synthetic chemical fertilizer kinds. Nearly 1% of India's GDP is currently going towards escalating fertilizer subsidy expenses. The most subsidy is given to urea compared to other fertilizers. With only extremely few applications of secondary nutrients (such as sulfur, calcium, and magnesium) or micronutrients (such as zinc, copper, iron, manganese, boron, and molybdenum), heavily subsidized urea is spread across the field. In contrast to the generally advised ratio of 4:2:1, the excessive application of urea resulted in a severely skewed NPK distribution ratio of 8.2:3.2:1. This imbalance has an impact on farmers' net income, agricultural productivity, and soil fertility, which ultimately leads to decreased biodiversity and severe water resource pollution (FAO 2014) [42]. Indian officials have previously deemed the deteriorating health of Indian soils and the threat they pose to food and nutritional security as a disaster (Gopikrishna 2012) [19].

Indian soils' single-plant nutrient shortage is now manifesting as multi-nutrient insufficiency. The primary reason for falling agricultural output and crop response ratio is the unbalanced use of plant nutrients and also their extraction. Secondary and micronutrient depletion in soil is another issue. The crop's ability to respond to NPK application is also being hampered by growing secondary and micronutrient deficiencies. Indian soils frequently lack at least 6 nutrients (N, P, K, S, Zn, and B). An annual N+ P_2O_5 + K_2O shortage of 8–10 million tons has been reported for a number of years (Shivey 2011) [61]. Sulphur, zinc, and boron deficiencies affect 42%, 48.5%, and 33% of the soils, respectively (Tewatia 2012) [70].

The consumption of fertilizer nutrients has increased over the past few years, but food grain output, in particular, has not increased in line with this trend. Beginning from April 1, 2010, the Indian government implemented a nutrient-based subsidy (NBS) on fertilizers containing phosphorus and potassium. It may result in significant adjustments to the fertilizer use pattern towards balanced fertilization (both in the short- and long-term). In order to increase soil and crop production, SSNM has grown become a significant problem. Thus, a critical challenge for future agriculture is the development of specialized and value-added fertilizers, particularly fertilizers supplemented with micronutrients.

Of the major problems emerged due to imbalanced fertilization major ones include:

Deficiencies of secondary and micro-nutrients in the soil (other than NPK)

Continuous nutrient mining from the native soil coupled with imbalanced use of fertilizers has caused rising deficiencies of secondary and micro-nutrients (Goud *et al*., 2013) [21]. Increased secondary and micronutrient deficiencies were caused by the extensive use of high analysis fertilizers and the neglectful use of organic fertilizers in the soils. Out of the 17 basic plant nutrients, nitrogen and phosphorus have received the most attention. Deficits of nitrogen, phosphorus, potassium, sulfur, zinc, boron, iron, manganese, and copper have been detected as a result, and their respective amounts are 89, 80, 50, 41, 48, 33, 12, and 3% (Tewatia *et al*. 2012) [70].

Low and declining crop response to fertilizers

Continuous use of fertilizer N combined with insufficient P and K application results in mining of organic P and K from the soil. Micronutrient and S deficits were caused by the use of high analysis fertilizers and an inadequate supply of organic manures. In India, crops are thought to mine roughly 28 million tons of basic plant nutrients each year, whereas only 18 million tons or even less are added as fertilizer, creating a net negative balance of about 10 million tons of primary plant nutrients (Patel *et al*. 2008). Sulphur, zinc, and boron deficiencies are becoming more prevalent and serious. In addition, applied N, P, K, Zn, Fe, and Ca usage efficiencies in Indian soils are 30-50, 15-20, 70-80, 2-5, 1-2, and 1-2, respectively (FAO 2005) [16]. As a result, the problem of nutrient deficits is exacerbated further due to the low efficacy of applied fertilizers, notably P and micronutrients. Kaleeswari concluded that customized fertilizers based on crop response are to be created in order to improve fertilizer use efficiency via balanced fertilization.

Other aspects

The uneven application of chemical fertilizers created various difficulties such as productivity stagnation, soil disease, widespread insufficiency of secondary and micronutrients, the growth of salt and alkalinity problems, and so on (Tewatia *et al*. 2012) [70].

4. Components of SSNM

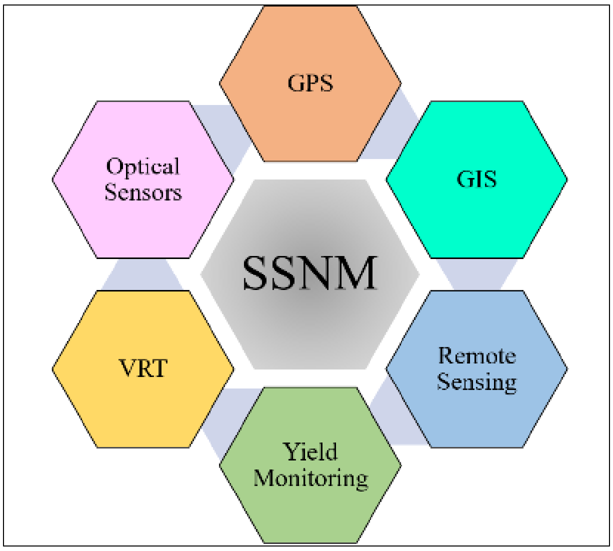

Fig 2: Components of SSNM

Through four important principles, SSNM works to improve supply of nutrients in soil over time and area to fit crop demands. The International Plant Nutrition Institute is credited with developing the "4 R's" ideas, which date back to at least 1988. These are given below:

Right product: To achieve a balanced delivery of nutrients, match the fertiliser product or nutrient origin to crop requires and soil type.

Right rate: Match the amount of fertiliser applied to crop requires, taking into consideration the soil's present supply of nutrients. Too much fertiliser results in environmental losses such as runoff, leaching, and gaseous emissions, and also financial waste. Too little fertiliser depletes soils, resulting in soil degradation.

Right time: Assess crop nutrient dynamics to ensure nutrients are accessible when crops require them. This may imply applying mineral fertilizers in two applications or mixing organic and mineral nutrient sources to offer slow-release nutrients.

Right place: Minimizing nutrient losses requires providing and retaining nutrients at the proper distance from the depth of the soil as well as crop to ensure crops can use those nutrients. In general, integrating nutrients to the soil is preferable to applying them on the top. The best method is determined by the soil, crop, tillage regime, and fertilizer type.

a) Global Positioning System

The 24 orbiting satellites that make up the global positioning system (GPS) produce radio signals that are picked up by GPS receivers. The mapping of soil and crop measurements is made possible by having exact information at all times. Users can return to a specified spot to sample or treat certain regions using GPS receivers, which can be carried into the field or attached on tools. In order to collect data and conduct farming operations, exact location is required. When it comes to crop production, numerous procedures are carried out to account for the internal variation in each field plot. These procedures include precision sowing, fertilizing, irrigating, controlling plant diseases, insect pests, and other issues. Although there hasn't been much GPS use in agriculture, it's reasonable to foresee widespread adoption in the future. A precision GPS Helicopter using GPS technology that can spray a zone as small as 4 x 4 meters has recently gained a lot of interest. Now, some forward-thinking farmers are starting to employ GPS to log their observations. The use of GPS systems in precision agriculture could assist Indian farmers in reaping the benefits of cutting-edge technology without sacrificing the quality of their crops and the land.

b) Remote Sensing

Collection of data from a distance is known as remote sensing. Simple hand-held gadgets, aircraft mounts, or satellite-based sensors can all be used as data sensors. The primary method used in precision agriculture to gather field data is remote sensing. It can provide decision-makers with interior information about a field plot, such as information about the patterns of crop growth, the state of crop growth, and spatial variability. Over the past 30 years, the method of agricultural remote sensing has continuously improved to a near-perfect state. It has the potential to be used in a wide range of fields, including the monitoring of soil moisture, crop nutrients, pest and disease activity, crop growth status, yield estimation, etc., and it can be a valuable information source for precision agriculture. To locate the soil, vegetation, and other criteria that are suitable for remote sensing, this is for the data acquisition of the farms.

c) Geographic Information System

GIS is a combination of computer hardware and software system that creates maps using feature attributes and location information. The ability of agricultural GIS to hold layers of data, including yield, maps from soil surveys, data from distant sensors, etc., is a key feature. This platform interacts with other users or systems by exchanging information. Generally speaking, the information service consists mostly of the services of information management, message exchange and updating, decision analysis, as well as data release.

d) Yield monitoring

Site-specific farming relies heavily on yield monitoring and mapping, which at first became the most popular features of precision farming (Heacox 1998) [24]. The most accurate way to determine the geographical yield variability that exists in agricultural fields is through yield monitoring, which enables farmers to evaluate how their management practises and the surrounding environment affect crop production (Stombaugh and Shearer 2000) [68]. The farmer receives immediate and insightful feedback from this assessment, helping them to make more effective choices (Pelletier and Upadhyaya 1999) [48]. Immediate yield and moisture records, the construction of yield and moisture maps, the documenting of digitally highlighted pests, and the organisation of data by year, farm, field, load, and crop are a few examples of this kind of feedback. A special GIS database developed by yield monitoring over time helps farmers discover yield variability within a field, improve variable-rate decisions, and build a history of spatial field data. Other crops like potato, onion, sugar beetroot and tomato are the subject of research and commercialization for this technology.

e) Variable Rate Technology

Agricultural inputs are modified using variable-rate technology (VRT) to meet site-specific needs in each area of the field. If machineries are used, variable-rate machinery is needed. Inputs can be manually applied on small farms. Application of variable rate technology (VRT) needed: a) Positioning correctly in the field, b) Correct data at the site, c) Farm equipment with VRT controllers may automatically manage the rate of the application according to pre-derived input distribution maps and can pinpoint the exact location for spatial variability in the field using a DGPS sensor. VRT technology has many uses in the management of site-specific cropping systems. The most popular precision agriculture technology is likely variable-rate application equipment. Around 1,600 flotation fertilizer distribution systems, map-driven variable rate technology (VRT) systems, and mobile sensor tractor application systems have been sold.

f) Optical Sensors

Optical sensors can be used by farmers and extension professionals to create SSNM recommendations, notably for N. The NDVI, which gauges the nutritional status of vegetation on the basis of their shape and color (green or yellow), is created by optical sensors that monitor reflectance from the leaves. Initially this technology was created for large farmhouses, but it is now commercially accessible in a small portable type that prices only a small portion of the earliest technology (around $ 500). The sensor must be locally calibrated for a specific nutrient, crop, and area before optical sensor-based nutrient management can be used. This calibration connects the crop's grain yield to the NDVI analyses. Optical sensors are required, after calibration is complete: 1) creation of a orientation band in a grower's land that will get unlimited amounts of nitrogen, 2) collecting an NDVI reading in the agricultural area where the farmer needs to know how much N ought to be sprayed, and 3) The NDVI data gathered in those 2 fields, along with the dates of sensing & planting, are incorporated into a scientific model established for each and every region. In several countries, such as China, India, Mexico, and Zimbabwe, such models have been recognized for usual crops (Crain *et al*. 2012) [11].

5. Approach and Methodology

The relatively recent method to nutrient advice is mostly based on indigenous soil nutrient supply and crop nutrient demand for reaching targeted output. The SSNM guidelines could be developed using only plant data or soil and plant analysis (Khurana *et al*. 2008) [32]. A set of quantitative properties known as indicators can be used to monitor and evaluate soil fertility. Environmental circumstances & nutrient status are two main categories for these indicators. Since the early 1990s, this principle has attracted extraordinary attention & applied in study fields such as species suitability determination, relations, community structure & niche formation. The idea for niche fitness has also been utilized in residents studies, urban economics, and other disciplines of research. This model, can indicate how well-matched crops are to the ecological conditions of the soil. It can also detect the indications that limit crop development (Sarkar *et al*. 2017) [57].

a) Plant analysis based SSNM

Status of the crop nutrient is considered as the best way to determine crop nutrient necessity and soil nutrient providing capability, the approach is based on plant analysis. Witt and Doberman proposed the five main phases of SSNM for developing field specific NPK sanctions in irrigated lowland rice, & they were then successfully utilized in more crops like wheat, sugarcane, maize, onion, and so on (Witt and Dobermann 2002; Dass *et al*. 2014) [78, 14]. These are as follows: (i) setting a production goal, (ii) estimating crop nutrient necessities, (iii) estimating native nutrient supplies, (iv) calculating fertilizer rates, and (v) dynamically adjusting N applications. The target yield is often believed to be 70-80% of the crop variety's potential yield (Y_{max}) or climatic-yield potential (CYP), it can be evaluated using a crop growth model. The nutrient necessities are calculated using quantitative evaluation of tropical soil fertility models. Indigenous nutrient supply is calculated in farmers' fields using the nutrient omission plot technique. INS is the total amount of a specific soil nutrient that is available to the crop during the cropping cycle in the absence of other non-limiting nutrients. Utilizing the nutrient gap and fertilizer recovery efficiency, field-specific fertilizer nutrient rates are computed. Phosphorus and potassium fertilizer rates are often applied as basic dosages, however nitrogen fertilizer rates are dynamically changed and applied based on crop needs at several important stages of crop growth. Site specific N management that is also in-season approach can help to close the N gap in crop output and also essential for agricultural sustainability & intensification. The SSNM approach has demonstrated the potential for raising crop yields & promoting NUE in rice, maize, wheat, and other crops (Dobermann *et al*. 2002; Tomar *et al*. 2016; Grzebisz and Lukowiak 2021) [14].

b) Soil with plant analysis based SSNM:

Fertilizer recommendations based on samples of soil or plant in a given field are known as site specific nutrient management & are widely used in worldwide agriculture (Cottenie 1980; Jones 1993; Farina 1994; Cantarella *et al*. 1998; Hergert 1998; Olfs *et al*. 2005) [10, 30, 17, 9, 25, 41]. Since the late 1960s, India has lobbied for fertilizer recommendations based on a "targeted yield approach," often known as SSNM (Ramamoorthy *et al*. 1967; Srivastava *et al*. 2016) [52, 64]. Grounded on soil and plant analysis information, it proposes the best fertilizer dose for crop yield targets using fertilizer adjustment equations or STCR equations. Different parameters, such as available nutrient level in soil, crop nutrient demands for a higher target yield, total nutrient consumed by crop in control plots, fertilized plots, and organic plots under field experiment, and nutrient recovery efficiency, are estimated in order to develop target yield equations or STCR based fertilizer alteration equations of a cropping arrangement in a particular area (Sekhon *et al*. 2012) [59]. For fertilizer prescription based on soil test and yield objective for agro-horticultural crops and important cropping sequences in Tamil Nadu's six agro-climatic zones, STCR equations were developed under the integrated plant nutrition system (TNAU, 2021) [69]. Site specific fertilizer doses were calculated using STCR equations to meet the nutrient requirements of the selected crop species while achieving the desired yield without depleting soil nutrient reserves (Mahajan *et al*. 2013) [36].

c) GIS based fertility mapping

Most countries are currently facing acute scarcity of agricultural land for food production due to the rapid growth in population and limited land resources. With the aim of increase output and productivity, progressively more chemical fertilizers are applied to farmland, resulting in soil & water pollution, fertility ruin, and nutrient disproportion, while modern technologies are used to promote sustainable food production and coordinated agricultural development. Extensive soil testing methodologies are required for the wide diffusion and acceptance of fertilizer sanctions via SSNM using the classical soil testing approach. Though, GPS & GIS based soil fertility mapping can give an affordable alternative that provides more accurate and effective nutrient managing for long-term food production. Samples are analyzed to determine soil quality & health. Following these approaches, the location data for the sampling point is integrated with that of the relevant attribute data in a GIS stand to build nonstop surface maps of the attribute. Each point on the map, constructed using interpolation methods, allows for the approximation of trait values based on latitude & longitude (Iqbal *et al*. 2005) [27].

Proper sampling and interpolation technique are two of the most essential variables determining to the achievement and precision of soil fertility mapping. To obtain expressive estimates, selection points must be taken on a grid narrow enough to seize soil variability. To date, grid selection is the most extensively used tool for characterizing soil variability. At the present time, soil fertility mapping on the basis of a GIS decision support tool aids within the research region, and the maps developed through this approach can provide a clear visual indicator of changing fertility scenarios over time. Aside from the technical and economic benefits of building such a system, once established, it can serve as an effective extension tool. Farmers are better able to apply fertilizer logically because they are more aware of how their crops fit into the landscape in terms of basic soil fertility. The use of science-based BMPs and RMPs by lots of farmers in their particular fields, crops, and seasons is proof that the SSNM program has been successful (Satyanarayana *et al*. 2011) [58].

d) Modern approaches of SSNM

Two critical SSNM strategies for variable rate application for manures and fertilizers are map-based and sensor-based techniques. The broad and core aspects of site-specific management technology include site data, already available technology & efficient management. Map based SSNM techniques include three main steps: (i) assessing soil and crop variability, (ii) managing variability, & (iii) evaluating variability (Verma *et al*. 2020) [75]. Based on the nutrient variability map & the site specific management zone, site-specific fertilization was advised (Gorai *et al*. 2017; Miao *et al*. 2018; Vasu *et al*. 2020) [20, 39, 74]. The sensor system monitors the necessary soil qualities or crop characteristics; the measured data is then utilized to calculate fertilizer using a specific algorithm, and the results are used to control the variable rate applicator (Gupta 2006; Larson *et al*. 2020) [23, 35]. N fertilizer supervision with proximal sensors has been broadly researched and practiced in different crops (Prakash *et al*. 2018; Padilla *et al*., 2018; Singh and Ali 2020) [51, 44, 3]. Remote sensing systems based on spectral and thermal techniques have the ability to scheduled N fertilization across broad regions by rapidly identifying nitrogen status in the canopy (Yousfi *et al*. 2019) [81]. Green Normalized Difference Vegetation Index and Soil Brightness estimates from remotely recognized images, combined with soil nitrogen & organic carbon datasets, were used to create a site-specific management zone. Furthermore, DSS provides users with rapid and smart farm supervision decisions; smartphone applications and web services accelerate the diffusion of SSNM technology to farming peoples (Cammarano *et al*. 2020) [8].

Table 1: Crop specific SSNM approaches

Sl. No.	Reference	Area of study	Crop Involved	Significant Findings
1.	Witt *et al*. 2002 [78]	China	Rice	Improve yield and NUE in irrigated rice
2.	Kumar *et al*. 2014 [33]	India	Maize	Harvest index and grain yield higher
3.	Singh *et al*. 2012 [62]	India	Cowpea	Improve growth, development & seed yield
4.	Biradar *et al*. 2006 [4]	India	Wheat	Improves RDF
5.	Biradar *et al*. 2006 [4]	India	Chickpea	Increase additional yield
6.	Srivastava *et al*. 2009 [66]	India	Sweet orange	Increase yield and improve quality
7.	Srivastava, 2013 [64]	India	Citrus	Improve shelf life
8.	Byju *et al*. 2016 [7]	India	Cassava	Increase yield & NUE
9.	Wood *et al*. 2003 [79]	Australia	Sugarcane	Fertilizer application according yield potential & soil health
10.	Yadav and Kumar, 2009 [80]	India	Potato	High plant height & increase tuber yield

6. Advantages and Disadvantages

SSNM in agriculture refers to the varied management of soils and crops in response to localized conditions within a field. SSNM, also known as "Grid Farming", "Farming by Soils", or "Variable Rate Technology (VRT)," is a fast-evolving group of technologies that allow farmers to manage their soils and crops while equipment moves across a field. SSNM is really about doing the right thing at the right time, in the right place, and in the right way. SSNM is therefore immediately appealing since it offers a way to enhance cropping systems' economic and environmental performance. SSNM is a new technology that is still in its infancy, despite the fact that its supporters will tout its enormous potential. As a result, at this point in its evolution, SSNM has both advantages and disadvantages that together describe the current position of SSNM for agriculture (Pierce *et al*. 1994) [50].

a) Advantages

Higher profits

SSNM, or Site Specific Nutrient Management, plays a critical role in increasing agricultural profits by methodically enhancing the delicate equilibrium between fertilizer supply & plant demand. SSNM greatly adds to yield augmentation and maintenance by providing a better coordinated approach to plant nutrition. The overall impact of SSNM is its exceptional ability to improve the efficiency with which plants utilize nutrients (Wang *et al*. 2007) [76]. This, in turn, causes a cascade of advantages, including a significant increase in returns on fertilizer investments. As a whole, SSNM transforms the agricultural landscape by increasing not only production but also the economic viability of farming endeavors (Ortiz-Monasterio and Raun 2007) [43].

Reduces N_2O emissions

Agriculture significantly contributes to environmental emissions, with nitrous oxide (N_2O) accounting for 70-90% of overall emissions. The use of nitrogen-based fertilizers is the principal source of these emissions. However, there are mitigation techniques available, such as the introduction of Site-Specific Nutrient Management (SSNM) practices. SSNM focuses on nitrogen application optimization by adapting it to the unique needs of crops. This method not only improves crop nitrogen utilization efficiency but also helps to reduce N_2O emissions. This is accomplished by reducing excessive nitrogen application, modifying application schedules, and minimizing nitrogen losses due to leaching, runoff etc.

Enhanced disease resistance

The greater resilience to plant diseases may result from the more balanced NPK nutrition provided by SSNM (Pasuquin *et al*. 2014) [46].

b) Disadvantages

Technology and knowledge requirements

SSNM necessitates an understanding of the underlying soil parameters as well as the ability to analyze crop nutrient status and modify fertilizer inputs accordingly. While the need for on-farm nutrient trials and soil tests has historically been a barrier to SSNM implementation, the growth of decision support systems and farmer-friendly tools and techniques that use proxy data to calculate nutrient requirements has made SSNM more accessible to farmers and farm advisors.

Fertilizers availability

The price and availability of fertilizers, either synthetic or organic, are not uniform. Though SSNM can support farmers make the most use of restricted nutritional resources, developing input markets may be required prior to acceptance.

Variable economic benefit

To improve growers' profitability, SSNM needs to provide either a) funds generated by reduced fertilizer practice without a decrease in yields, or b) yield rises worth more than the expenses of getting and implementing SSNM skill. Farmers have a better chance of earning good net returns while growing cash crops, where production gains can significantly boost profitability.

7. Conclusion

Site Specific Nutrient Management (SSNM) is a strategy that focuses on precision nutrient application in diverse crops. It entails delivering nutrients based on crop specific demands while taking regional variability into account, resulting in efficient nutrient utilization, less fertilizer waste, and reduced environmental impact. Crop yields can improve, but nutrient input is often reduced. Soil and plant nutrient sensors, remote sensing, GIS, decision support systems, and variable nutrient application gear are all used in this strategy. It is a promising technology for improving agricultural economic and environmental consequences. It is full of obstacles and uncertainties, with continual innovation and knowledge development being a fundamental feature. The application of SSNM tackles issues such as nutrient deficits, soil health degradation, and the effects of climate change on agriculture. While the technique has demonstrated improvements in production and nitrogen use efficiency, its adaptability to a variety of climates must be considered. A streamlined approach that combines site-specific judgements with regional goals could be ideal. To prevent additional nitrogen depletion in agricultural soils, efforts must be made. Managing soil nutrient balances is critical, and it requires the collaboration of political leaders, planners, legislators, financial institutions, and nutrient providers. Irrational crop management and overuse of fertilizers have resulted in lower nutrient usage efficiency, crop yields, and farmer profitability. Adopting SSNM, which includes technology such as soil testing, remote sensing, and decision support systems, has the potential to increase food production in an efficient and sustainable manner. Effective SSNM can improve fertilizer efficiency, output, and reduce environmental consequences. Nitrogen management and its effects on greenhouse gas emissions must be carefully considered. The propagation of SSNM should focus on enhancing profitability through improved yields and reduced input costs. Interdisciplinary collaboration spanning biology, mechanics, electronics, and other domains is required for the development of SSNM. This innovative initiative attempts to create precision agriculture, in which crops are cultivated and provided with defined quality throughout their lifecycle utilizing modern procedures. Finally, by customizing fertilizer inputs to crop demands and spatial heterogeneity, Site Specific Nutrient Management holds potential for precision agriculture. It has the ability to increase yields, reduce environmental impact, and contribute to long-term agricultural practices. However, problems remain, necessitating interdisciplinary collaboration and targeted interventions in order to achieve widespread adoption and execution.

8. Reference

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