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Vedhika Sahu
Ph.D. Scholar, Department of Soil Science & Agricultural Chemistry, Indira Gandhi Krishi Vishvavidyalaya, Raipur, Chhattisgarh, India

VN Mishra
Professor, Department of Soil Science & Agricultural Chemistry, Indira Gandhi Krishi Vishvavidyalaya, Raipur, Chhattisgarh, India

Purnendra Kumar Sahu
Senior Research Fellow, PFDC, Department of Fruit Science, Indira Gandhi Krishi Vishvavidyalaya, Raipur, Chhattisgarh, India

Correspondence
Vedhika Sahu
Ph.D. Scholar, Department of Soil Science & Agricultural Chemistry, Indira Gandhi Krishi Vishvavidyalaya, Raipur, Chhattisgarh, India

Soil test based fertilizer recommendation for targeted yield of crops: A review

Vedhika Sahu, VN Mishra and Purnendra Kumar Sahu

Abstract
This paper reviews the recent scientific investigation carried out in various parts of India on soil test based fertilizer use for achieving the targeted yield of crop. Soil testing has been accepted as a unique tool for rational fertilizer use. It helps to assess the soil fertility status and recommend suitable and economic nutrient dose through chemical fertilizer and organic manure for different crops and cropping system. The selection of proper rate of plant nutrient addition is influenced by knowledge of nutrient supplying power of the soil and efficiency of fertilizers. Fertilizer recommendation based on soil test have been evolved for many crops and cropping system using post-harvest soil test value.

Keywords: soil test, fertilizer, recommendation, unique, rational, crop.

Introduction
Soil testing as a tool for judicious fertilizer use is a well-recognized practice all over the world which takes care of too little, too much or disproportionate applications of nutrients. The soil testing and fertility management programmes have been given adequate importance for sustaining crop production and balanced fertilization in Indian agriculture. Fertilizer has been and will continue to be the key input for achieving the estimated food grain production goals of the country. But, the escalating cost coupled with increasing demand for chemical fertilizers and depleting soil health necessitates the safe and efficient method of nutrient application. The soil test based fertilizer recommendation is therefore the actual connecting link between research and its practical application to the farmers fields. A farmer who follows only the soil test based fertilizer recommendations is assured of a good crop. Soil testing is essential and is the first step in obtaining high yields and maximum returns from the money invested in fertilizers. A fertilizers recommendation from a soil testing laboratory is based on carefully conducted soil analyses and the results of research on the crop, and it therefore is more scientific information available for fertilizing that crop in the field.

Fertilizer is one of the costliest inputs in agriculture and the use of right amount of fertilizer is fundamental for farm profitability and environmental protection (Kimetu *et al*., 2004) [18]. Dumping of fertilizers by the farmers in the fields without information on soil fertility status and nutrient requirement by crop causes adverse effects on soil and crop regarding both nutrient toxicity and deficiency either by overuse or inadequate use (Ray *et al*., 2000) [28]. Managing the location specific variability in nutrient supply is a key strategy to overcome the current mismatch of fertilizer rates and crop nutrient demand in irrigated rice environments (Dobermann and Cassman, 2002) [9]. To enhance farm profitability under different soil-climate conditions, it is necessary to have information on optimum doses for crops. Traditionally, to determine the optimum fertilizer doses of most appropriate method is to apply fertilizer on the basis of soil test and crop response studies. Improved crop management needs to be envisaged with adequate emphasis on balanced plant nutrition for stability in production, appropriate soil nutrient resilience. With the advent of fertilizer responsive improved varieties, indiscriminate application of fertilizer nutrients becomes an obvious problem in the quest for ever higher crop yields (Ingram, 1995) [15]. Concurrently, an escalating trend in fertilizer use is forseen, which in turn increases the unit cost of production. Most often, prior estimation of the actual nutrient requirement of a particular crop, native soil fertility status, has been ignored. Soil test based fertilizer use is must for sustainable agriculture (Rao and Srivastava, 2000) [26]. Thus, need-based estimation of N, P, and K requirements may call for soil test crop response (STCR) based nutrient management, which can be represented in a linear rela- tionship, correlating their requirement with a specified target yield depending on their native soil status. The fertilizer application by the farmers in the field without knowledge of soil fertility status and nutrient requirement of different crops usually leads to adverse effect on soil as well as crops by way of nutrient deficiency or toxicity due to over use or inadequate use of fertilizers. In this regard, targeted yield approach has been found to be beneficial which recommends balanced fertilization considering available nutrient status in the soil and the crop needs. Targeted yield approach was first developed by Troug (1960) [39] Ramamoorthy *et al*. (1967) established theoretical basis and experimental technique to suit it to Indian conditions. This target yield equation (TYE) is considered as a soil-and fertilizer-based precision farming strategy to meet nutrient demands for a specified yield (Balasubramanian *et al*., 1999) [2].

Location specific fertilizer recommendations are possible for soils of varying fertility, resource conditions of farmers and levels of targeted yield for similar soil classes and environment (Ahmed *et al*., 2002) [1]. Field specific balanced amounts of N, P, K were prescribed based on crop based estimates of the indigenous supply of N, P and K and by modelling the expected yield response as a function of nutrient interaction was done by many workers (Dobermann and White 1998; Witt *et al*., 1999) [10, 43]. Fertilizer recommendation for preset yield target is refined technique particularly applicable under conditions of fertilizer resource constraint for most efficient use of fertilizer and soil nutrients (Ramamoorthy and Velayutham, 1971). In this technique, the fertilizers are recommended separately for different fields separately on the basis of soil test and are preset uniform yield targets depending upon the availability of fertilizer input.

Inductive approach and STCR field Design

Recognising the reported lack of correlation between soil test and crop response to fertilizer in multi-location agronomic trials and the need for refinements in fertilizer prescriptions for varying soil test values for economic crop production in the wake of Green Revolution era, Ramamoorthy (1968) designed a novel field experimentation methodology for Soil Test Crop Response correlation studies and initiated the All India Coordinated research Project of the Indian Council of Agricultural Research (ICAR) in 1968. The principle of the methodology is that to develop a quantitative relationship between different measured levels of any one component (eg. fertilizer N) of a crop production system and the yield obtained from that system, it is necessary to conduct a field experiment with different measured levels of that factor and to measure the resultant yield.

In soil test crop response studies, it is necessary to have data covering the appropriate range of values for each controlled variable (fertilizer dose) at different levels of the uncontrolled variable (eg. soil fertility). Since different levels of the uncontrolled variable (eg. soil fertility) cannot be expected to occur at one place, normally different sites are selected to represent the different levels of soil fertility and the inference is deduced and applied in general.(Deductive approach). In the Inductive Approach of STCR field experimentation, all the needed variation in soil fertility level is obtained not by selecting soils at different locations as in earlier Agronomic trials, but by deliberately creating it in one and the same field experiment in order to reduce heterogeneity in the soil population (types) studied, management practices adopted and climatic conditions.

Ramamoorthy and Velayutham (1971, 1972 & 1974) [25] have elaborated this Inductive approach and the STCR field design, which is also quoted by Black (1993). A field, representative of the major soil type in the region, having low soil fertility level is selected and divided into four equal strips. While the first strip receives no fertilizer, the second, third and fourth receive half, one and two times the standard dose of N, P and K respectively. The standard dose of P and K are fixed taking into account the P and K fixing capacities of the soil. A short duration exhaust crop is grown so that the fertilizers undergo transformations in the soil with plant and microbial activity. After harvest of this exhaust crop, each of the strips is divided into sub-plots. Twenty one selected treatment combinations from 5x4x3 levels of N, P and K, in addition to 6-8 controls are randomly allotted in each of the four strips and the test crop for which soil test calibration is required is grown to maturity, following standard agronomic practices. Before the application of fertilisers, soil samples are collected from each sub-plot and analysed for available nutrients by different soil test methods. After harvest, grain and straw yield and total nutrient uptake are also determined plot wise.

In order to reduce the cost of cultivation and also to keep the soil health and fertility in better condition to sustain the productivity, there is an urgent need to find out some alternate sources of nutrients. A fertilizer use program with INM approach tuned to soil fertility levels and crop requirements ensures that only benefits of fertilizer use are delivered on farm and successful use of this technology has already been demonstrated on farmer's fields over years (Subba Rao and Srivastava, 1998). In the light of ever increasing prices coupled with increasing demand of chemical fertilizer and depleting soil fertilizer necessitates the integrated use of organic (renewable) and inorganic (non-renewable) sources of nutrient for sustainable crop production and better soil health. Therefore, there is a need for improvement of input use efficiency through proper integration of chemical fertilizer with organic manure, by balanced nutrition of crop.

Importance of Soil Testing

Fitts and Nelson (1956) [11] defined some of the more important objectives of soil test as grouping of soils into classes for purpose of fertilizer and lime requirement, prediction of the probability of getting a profitable response to the application of fertilizer nutrients and the determination of specific conditions that may be improved by cultural practices. In view of all these, Kanwar (1971) [17] has referred "Soil testing as the key weapon in the armory of a soil scientist".

The importance of soil testing is aptly stated by Tisdale (1967) [38] as "Soil testing is to the art of crop production what the thermometer is to the medical profession". A soil test chemically extracts and measures the elements essential to plant nutrition. It also measure soil acidity or alkalinity through pH. These factors are indicator of requirement, nutrient availability and potential of the soil to produce crops (Tucker and Carter, 1998) [40]. It is a proven technology for optimum resources, utilization and profitable yield.

A soil test value itself has no real meaning until it is correlated with crop response and interpreted in a proper manner to give fertilizer recommendation. Kanwar (1971) [17] has termed soil test as a gimmick unless it gives a correct appraisal of fertility status and predicts fertilizer required for maximum return or a definite yield goals. Melsted and Peek (1977) [20] stated that soil testing results indicate nothing about the potential of soil to produce or amount of nutrients to be added to achieve a desired yield. The interpretation of test results is carried out by correlating data obtained by analysis of soil samples with known field crop response. The accuracy of interpretation depends on the quality of field research work and response of crop to different soil nutrient levels. Calibration and correlation was used by Welch and Wiese (1973) [43] to express the relationship between the soil test results and nutrient uptake of plant. The term calibration was used to express basic principles of relationship between soil test results and yield responses observed from increasing amounts of nutrient applied. Calibration was defined by Cope and Rouse (1973) [7] as a process by which relation between soil test value and crop yield is obtained.

Berger (1954) [3] proposed a new approach to fertilizer prescription based on available nutrient status of the soil for specific crop yield goals taking into account the nutritional requirement of crops and the nutrient supply from soil and fertilizer sources. He also reported the values of nutritional requirement of corn, soil and fertilizer efficiencies presented a simple way of calculating fertilizer requirements. Soil testing gives precise and quantitative information about fertilizer use to get maximum return. For the accuracy of soil testing as simple laboratory exercise may become a complicated prescription and effectiveness of test result must be judged from actual field performance (Mahajan *et al*., 1995) [25]. Soil testing provides sound information about the fertility and productivity of soils. This enables the farmers to make the most profitable use of some of the costly inputs in farming (Sekhon and Velayutham 2002) [31].

Soil Test Crop Response Based Fertilizer Application

Soil test crop response (STCR) approach takes into account, the amount of the nutrient removed by the crop, initial level of soil fertility, efficiency of nutrient uptake from the soil and fertilizers. The fertilizer dose based on this method is designed to maintain soil fertility and reduce fluctuations in yields. The first systematic study in the country to relate knowledge of soils to the judicious use of fertilizers was made by Stewart (1947) [35]. Based on this study fertilizer use project was started during 1953 and soil testing laboratories were started during 1955-1956. Consequently in 1957, model agronomic experiments on experimental farms and simple fertilizer trials on cultivators fields were introduced. With the establishment of soil testing laboratory, soil test-crop response correlation work was started at the Indian Agricultural Research Institute, Pusa, New Delhi. This work formed the basis for selection of soil test methods and divided soil test values into three categories as low, medium and high.

With the introduction of fertilizer responsive high yielding varieties and hybrids of crops, intensification of cropping under expanded irrigation facilities during 1960's and the general fertilizer recommendations themselves being on the higher order, the interpretation of soil test ratings and fertilizer recommendation by soil test laboratories needed to be reoriented to suit the modern agricultural technology by generating soil test calibration research work. With this background, ICAR initiated the All India Co-ordinated Research Project on soil test crop response correlation during the fourth five year plan (1967-68). The studies under the project provide quantitative relationship for adjusting fertilizer doses with varying soil test values for obtaining targeted yield of crops

Soil test crop response approach is based on the three basic requirements i.e., quantity of nutrients required in kg per quintal of economic yield, the percentage contribution of nutrients by the soil and the contribution of nutrients through the fertilizers to optimize the yield. Another added advantage is the estimation of fertilizer nutrients required to be added for different soil test values of nutrients and targeted yields. This approach is based on the principle of Leibig's law of minimum.

Liebig's law of minimum states that the growth of plant is limited by the plant nutrient element present in the smallest amount, all others being in adequate quantities. From this it follows that a given amount of a soil nutrient is sufficient for any one yield of given percentage nutrient composition. Ramamoorthy *et al* (1967) established the theoretical basis and experimental proof for the fact that Leibig;s law of minimum operates equally well for N,P and K. This forms the basis of fertilizer application for targeted yields, first advocated by Troug (1960) [39]. The yield targeting method is unique in the sense that this method not only indicates soil test based fertilizer dose but also the level of yield the farmer can hope to achieve if good agronomical practices are followed in raising the crop. The essential basic data required for formulating fertilizer recommendation for targeted yield are

- Nutrient requirement in kg/q of produce, grain or other economic produce.
- The percent contribution from the soil available nutrient.
- The percent contribution from the applied fertilizer nutrient.(Ramamoorthy *et al*.,1967)

The above mentioned three parameters are calculated as:

Nutrient requirement of N, P and K for grain production

Kg of nutrient/q of grain = Total uptake of nutrients (kg)/ Grain yield (q)

$$\text{a) Kg Nutrient per quintal grain production (NR)} = \frac{\text{Uptake of Nutrient in kg ha}^{-1}\text{ from grain + straw}}{\text{Grain yield in q ha}^{-1}}$$

Contribution of nutrient from soil

$$\text{b) Contribution of Nutrient from soil (Es)} = \frac{\text{Uptake of Nutrient (kg ha}^{-1}\text{) from grain + straw from control plot}}{\text{Soil test value for available Nutrient (kg ha}^{-1}\text{) from control plot}}$$

Contribution of nutrient from fertilizer

$$\text{(c) Percent Contribution of Nutrient from fertilizer } (E_f) = \frac{\text{Total uptake Of nutrient In kg ha}^{-1} - \text{Soil test values of fertilizer treated plots} \times \text{Contribution of nutrient from soil}}{\text{Fertilizer nutrient applied}} \times 100$$

Calculation of Fertilizer dose

The above basic data are transformed into workable adjustment equation as follows:

$$F = \left(\frac{NR}{E_f} \times Y\right) - \left(\frac{E_s}{E_f} \times SN\right) - \left(\frac{E_{FYM}}{E_f} \times FYM\ (t\ ha^{-1})\right)$$

Where,

F = Fertilizer (kg ha-1)
NR = Nutrient requirement
Es = Per cent contribution from soil
Ef = Per cent contribution from fertilizer
E_{FYM} = Soil test value (kg ha-1)
STV = Per cent contribution from FYM
Y = Yield target (q ha-1)
FYM = Farmyard manure (t ha-1)

This tool is likely to have a much wider adaptability to suit the targeted yield goals by a farmer depending upon the investment capacity on nutrients and their availability in the soil, the goals to maximize the production, profit per unit area and profit per rupee invested on the fertilizer nutrients in proportion to the returns from the produce with maintenance of soil fertility.

Formulation of Fertilizer prescription Equations

Soil test based fertilizer recommendation calibrate on the logic that nutrient requirement of the crop minus nutrient supplied by soil should be the fertilizer needed. It requires estimating the amount of nutrient removed by a crop for a certain yield level and the contribution of nutrient from the soil source, then finally the amount of fertilizer to be added to meet the requirement of crop is calculated considering the efficiency of fertilizer. This approach provides the basis of optimum resources utilization and balance crop nutrient management.

Truog (1960) illustrated the possibility of 'Prescription method' of fertilizer use for obtaining high yields of Maize using empirical values of nutrient availability from soil and fertilizer. Target yield approach has to be used to formulate fertilizer recommendations across the country (Santhi *et al.*, 2004) [30]. Berger (1973) [3] suggested that three basic parameters i.e. nutrient requirement, soil efficiency and fertilizer efficiency must be considered for fertilizer prescription. The dimensions, scope and prospects of fertilizer recommendation based on the concept of yield targeting were documented by Randhawa and Velayutham (1982). Reddy *et al.* (1989) have documented the integrated nutrient management derived from the above mentioned approach for wheat, sunflower, rapeseed, cotton and jute grown in different soils. Subba Rao and Srivastava (2001) have documented the soil test based fertilizer recommendations for targeted yields of crops in the Coordinated STCR project.

Sonar *et al.* (1982) [34] conducted experiment on a Vertic Ustropepts at Rahuri during *kharif* 1976 with sorghum as test crop and worked out NR (kg q-1), CS (%) and CF (%). Using these parameters, fertilizer adjustment equations were developed and tested under field conditions at four locations. Based on the results, they reported that application of fertilizers using fertilizer adjustment equations for yield targets of 40, 50, and 60 q ha-1 resulted in higher yields and benefit cost ratio than the application of general recommended fertilizer dose. The experiment conducted by Milapchand *et al.* (1984) [21] to test the validity of targeted yield concept for rice crop in the cultivators field showed that the actual yields obtained against different targets were within ± 5 and ± 10 per cent range for 70 and 23 per cent of the cases, respectively.

Dev *et al.* (1985) working on STCR approach in wheat obtained the mean grain yield of 35.0, 37.5 and 43.3 q ha^{-1} against the target of 35, 40 and 45 q ha^{-1}, respectively and the average yield obtained in 56 experiments for general recommended doses was 39.6 q ha^{-1}. These results showed that soil test based yield targets of wheat were obtained with in ±10 per cent of the deviations of the target in majority of the experiments. These results, therefore, suggest that adjustment equation for knowing soil test based fertilizer hold good and they could be safely used to advise farmers on fertilizer usage in wheat.

Kadam and Patil (1999) [16] reported that the yield targets of 80, 100 and 120 t ha^{-1} for seasonal sugarcane and 100, 125 and 150 t ha^{-1} for pre-seasonal sugarcane and 150, 175 and 200 t ha^{-1} for adsali sugarcane were achieved with fertilizer application on the basis of fertilizer adjustment equations.

Suri and Verma (1999) [36] reported that fertilization based on targeted yield concept in maize – wheat system was superior to both state level general recommendation and soil test based approaches.

Sharma and Singh (2000) [33] developed the fertilizer adjustment equations obtained from basic data for achieving targeted yield of wheat; FN = 4.86 T - 0.47 SN, FP_2O_5 = 2.92 T - 4.37 SP and FK_2O = 2.20 T - 0.26 SK where, T denote yield target in q ha^{-1}. They conducted a replicated follow-up field trial at IARI farm and applied the fertilizer dose from targeted yield equations for the soil for achieving the yield target of 42.53 q ha^{-1} of wheat grain was 103, 53 and 43 kg ha^{-1}. The yield obtained by targeted yield treatment was 44.17 q ha^{-1} as against the targeted yield of 42.53 q ha^{-1}.

Bera *et al.* (2006) carried out soil test crop response correlation studies in IR-36 to quantify rice production in the context of the variable use of balanced fertilizers based on targeted yield concept. Soil fertility status for N was low to medium (224-348 kg ha^{-1}), P was medium to high (87-320 kg ha^{-1}) and K ranged from medium to high (158-678 kg ha^{-1}). Nutrient requirement in kg t^{-1} of grain produce (NR), the per cent contribution from the soil available nutrients (CS %) and the per cent contribution from the applied fertilizers (CF %) were computed for calibrating and formulating fertilizer recommendations. The percent achievement of targets aimed at different levels was more than 90%, indicating that soil test based fertilizer recommendation approach was reasonably reliable.

Soil test based fertilizer prescription equations under Integrated Plant Nutrition System (STCR-IPNS) in Ultisols was worked out by Gayathri *et al.* (2009) [12] for potato. Making use of these equations, monograms were formulated for a range of soil test values and desired yield targets of potato. These equations were validated on farmers fields and it was found that the per cent achievement of the targets aimed was more than 90. The STCR-IPNS for 40 t ha^{-1} recorded relatively higher response ratio (38.05 kg kg^{-1}) and benefit–cost ratio (15.3) over other treatments indicating the validity of the equations for prescribing fertilizer doses for potato.

Santhi *et al*. (2010) [29] documented in a handbook on soil test and yield target based integrated fertilizer prescriptions, for a range of 41 crop situations in Tamil Nadu. One such example from this hand book, for integrated nutrient management for Rice on Noyyal Soil Series is given as FN = 4.39 T – 0.52 SN – 0.80 ON, FP_2O_5 = 2.22 T – 3.63 SP – 0.98 OP, FK_2O = 2.44 T – 0.39 SK – 0.72 OK; where ON, OP and OK are the N, P&K nutrients supplied through organic source.

Brajendra *et al*. (2012) reported that the fertilizer adjustment equations and a ready reckoner for optimum fertilizer doses at varying soil test values for attaining yield target of 40 and 50 q ha^{-1} of maize yield have been calibrated based on the targeted yield concept. Using these fertilizer equations, four field experiments with maize were conducted during *Kharif* 2006 at different locations in farmer's fields. The experiments indicated that it is possible to target the maize yield up to 45 q ha^{-1}.

Mishra *et al*., (2013) gave the fertilizer adjustment equation for tomato (cv, BT-10) under rice-tomato cropping system in an Ustochrept of Odisha. The fertilizer adjustment equations are FN = 1.32T – 0.45SN, FP_2O_5 = 0.72 T – 1.72 SP and FK_2O = 0.92 T - 0.96 SK where, T denote yield target in q ha^{-1}. It was observed that with increase in graded doses of fertilizer the tomato fruit yield increased with increase in fertility strip 149.4, 162.7 and 175.8 q/ha in L_0, L_1 and L_2 respectively.

Sharma *et al*., (2015) gave soil test based optimum fertilizer doses for attaining yield targets of rice under midland alfisols of Eastern India. Soil fertility status was poor to medium for N (194-283 kg ha^{-1}) and P (7.53-19.66 kg ha^{-1}) and medium to good for K (226-320 kg ha^{-1}). Based on the basic parameters (viz, Nutrient requirement, Efficiency of Fertilizer, Efficiency of soil, Efficiency of organic manure) the fertilizer adjustment equation was calibrated for rice to achieve a definite yield target. FN = 4.28Y – 0.44SN – 0.18 FYM, FP = 1.32Y – 2.92 SP – 0.14FYM, FK = 1.84Y – 0.17SK – 0.16 FYM.

Gogoi and Mishra (2015) formulated the fertilizer prescription equation based on targeted yield of pumpkin. The results showed that fertilizer rates increased as yield targets of pumpkin increased and the fertilizer rates decreased as the initial soil test level increased. Fertilizer adjustment equations developed are FN = 4.94 T – 1.25 SN, F P_2O_5 = 2.67 T – 2.71 S P_2O_5, F K_2O = 2.02 T – 0.55 S K_2O. The targeted yield approach was also found superior to fertilizer doses prescribed by soil testing laboratories. Similar results were also reported by Bera *et al.,* (2006) on farm evaluation of site specific nutrient management in pearl millet based cropping systems on alluvial soils. Similarly Santhi *et al.,* (2010) [29] also reported that under IPNS, required dose of fertilizer to achieve desired yield targets are reduced.

Thus the targeted yield approach of fertilizer recommendations ensures nutrient balancing to suit the situations involving different yield goals, soil fertility and resources of the farmer (Dev et al, 1985) [8]. Several workers have used this approach of fertilizer prescription (Rashid *et al*., 1988; Powelson et al, 1989; Yuam and Haung, 1995) [44]. Fertilizer adjustment equations based on soil test have been formulated for different crops under varying soil and climatic condition and widely reported in literature. (Tamboli *et al*. 1996; SelvaKumari *et al*., 2000) [37, 32].

Conclusion

The relevance and value of soil testing increases by choosing the yield target at such a level so that the cost of fertilizer requirement becomes more or less same as what was being practiced by the farmer already. When fertilizer availability is limited or the resources of the farmers are also limited, planning for moderate yield targets, which are at the same time higher than the yield levels normally obtained by the farmers, provides means for saturating more areas with the available fertilizers and ensuring increased total production also. The consequence of this approach – Ramamoorthy and Velayutham, (1974) [25]; Velayutham *et al.,* (1985) [41] shows that fertilizer use efficiency and the total production are higher when the available fertilizers are applied for low yield targets rather than arbitrary reduction in fertilizer dose.

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