Fertilizer Role in Sustainable Cotton Production

M.N.A. Malik
Central Cotton Research Institute, Multan, Pakistan

ABSTRACT

Fertilizer is a fundamental component of modern crop production systems. A balance must be maintained between production, profitability and conservation of soil natural resources for future crop production for cotton to be sustainable. Fertilizer is a kingpin in achieving this goal at global level. Cotton may not appear to be an exhaustive crop in terms of nutrient removal from the soil but is, in fact, highly inefficient in nutrient utilization in producing seedcotton yields. Fertilizers reward growers when applied intelligently according to crop needs but have an adverse effect when mismanaged. Fertilizers are inputs where a "little more" can be detrimental to yield. Poorly timed and inappropriate application methods can negate benefits from fertilization. Cotton in general is a well fertilized crop. Nitrogen, phosphorus and potassium are commonly added in most soils. The application of secondary and micro-nutrients to cotton is negligible in most parts of the world. Although crop response to nitrogen is consistent, predicting of response in cotton to most applied soil nutrients is unreliable because of the indeterminate growth habit of the cotton plant and its sensitivity to environmental conditions. Benefits from fertilization in cotton will always be dependent on crop management practices. Pest management and weed control particularly interact with fertilization in reaching profitable yields. Fertilization for sustainable cotton production is a farming systems problem. Better yields and quality in cotton require balanced nutrition, based on accurate fertility information and integrated farm planning. Further research in cropping systems, soil characterisation, plant analysis techniques and an understanding of the physiology of the cotton plant is needed to develop cost effective, sustainable production systems.

Introduction

Cotton is the major world fiber crop. It was grown on 33.7 million ha, producing 20 million tons of lint with a yield of 577 kg/ha in 1997. Cotton production worldwide has increased three fold during last 50 years; fertilizer and pesticides being major contributors to yield. However, cotton faces new challenges that threaten sustainability for future generations.

Sustainable development is a key issue in modern agriculture systems. Sustainable cotton production calls for maintained and enhanced yield levels without jeopardising the natural resource base of agriculture. Soil is a primary natural resource base and its health and fertility must be maintained for sustainable yields.

Yields of crops are limited by the availability of plant nutrients. Fertilizers can raise soil fertility, increasing the soil capacity to produce more food and fiber for present and future generations. The addition of fertilizers to soil is technically appropriate, economically viable and socially acceptable for sustained agricultural development. Use of fertilizer ensures conservation of natural resources, minimising soil degradation and providing farmers with an opportunity for economic crop production.

The principles of fertilizers use are straight forward but efficient use is complicated, involving the correct choice of type and amount of fertilizer with correct decisions on timing and method of application. The balanced supply of nutrients is a key to efficient crop management. This paper gives an overview of different aspects of fertilizer use in cotton production and assesses research needs of the 21st century.

Plant Nutrients Supply and Cotton Production

Plants depend on mineral nutrients for growth and development. For optimum growth and yield, nutrients must be available in the soil in an appropriate and balanced amount at the right time and right place. Mineral fertilizers and organic manures are the main source of plant nutrients, contributing to about 50% of yield improvements in developed economies and 75% in developing economies (Cooke, 1986; Krauss, 1997). The contribution of fertilizers to yield has been estimated at about 56% under rainfed and 102% under irrigated agriculture in cotton (Mathieu, 1979; Tandon, 1994; Malik, 1995b).

Fertilization is of limited value where water is inadequate. Rainfed cotton receives about 40 to 80 units of nutrients, while irrigated cotton receives 100 to 200 units of nutrients (Fig. 1). Israel and China lead the world in fertilizer use on cotton.

Optimum nutrient supply leads to higher cotton yields but maximum yields can be expected only in properly managed cotton crops. Australia and Pakistan use similar amounts of nutrient per unit of land but yields

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in Australia are almost twice those of Pakistan (Fig. 1). This indicates an interaction between plant nutrition and better crop production practices, such as high yielding varieties, efficient irrigation, better weed control and pest management. Climatic conditions and edaphic factors play an equally important role. Fertilizer and water must be judiciously applied in conjunction with other crop management practices to promote optimum, cost effective cotton productivity. (El Zik and Frisbie, 1985).

Chemical Composition of Cotton Plant and Nutrient Uptake

The chemical analysis of cotton pant at maturity is very important to know nutrient uptake and to formulate tactics for future fertility management. The chemical composition of cotton plants at Multan, Pakistan are summarised in Table 2.

Cotton plant parts differ widely in chemical composition. Seed is the main reservoir of most nutrients while lint is poor (Bassett and Anderson, 1970; Halevy, 1976). Cotton crop, therefore, is not considered very exhaustive in terms of nutrient depletion from soil (Hake et al, 1991). Plant nutrients removal for one tonne of economic yield for eight commercial crops clearly bears this out (Fig-2). Soybean, sunflower and cereals are far more exhaustive than cotton. The long term cultivation of cotton on the same land is unlikely to seriously deplete soil nutrients, if above ground plant parts, gin trash and seed are returned to soil.

Soil nutrients uptake in cotton plants is directly proportional to the dry matter production. Nutrients uptake is limited early in the season by lower dry matter production and late in the season by carbohydrate deficiency of roots. Maximum uptake, constituting 75% of the total uptake of N, P and K occurs during boll setting period (Malik, 1995a). The nutrients removed by the crop to produce one tonne of lint are given in Table 3.

These data indicate that after ginning, mineral nutrients make up > 2 percent of lint yield. This allows cotton to be grown with limited fertilizer input. When higher fertilizer rates are required to obtain optimum yield either cotton black box "roots" have not proliferated the soil properly or nutrient availability is limited by edaphic factors. By understanding the basics of nutrient uptake and utilization, a fertility programme can be designed to avoid these deficiencies.

Fertilizer Recommendations

Cotton is grown under a wide range of climatic, soil and cultural practices. Soil types range from sandy loam to silty clay loam with a pH range of 6 to 8, free of excessive salts and with good drainage. It is difficult to generalise fertilizer recommendations. Cotton is generally well fertilized, fertilizer consumption running parallel to the area cultivated. (Table 4).

Nitrogen contributes a major share in fertility management, followed by phosphorus and potassium. The use of secondary and micro-nutrients, viz., boron zinc and sulphur is recommended in some regions. Organic manures are common in China and India (ICAC, 1996, Silvertooth, *et al.*, 1992).

Nutrition Problems and Fertility Management in Cotton

Cotton nutrition problems are wide ranging because of difference in soil type, variety, climate and farmer's socio-economic conditions (Peasant vs mechanised farming). Standard management schemes, therefore, cannot be devised for world-wide application. the strategies to solve nutrition problems have to be multifaceted and mechanistic. The principles of maintaining soil fertility and productivity are dealt with only in a conceptual manner to optimise cotton yields world-wide.

Nitrogen

The most commonly used fertilizer in cotton production is Nitrogen because of its high demand by the plant and its low availability in the soil. Fields that do not respond to additional N fertilization are rare. Only where extremely high nitrogen levels have been established, would additional nitrogen fertilization be considered unnecessary. The prediction of the exact amount of nitrogen fertilizer that a cotton crop will need in advance of the season is usually complicated by the extremely dynamic nature of cotton plants and the sensitivity in its responses to other environmental conditions. In general, nitrogen is prescribed on the basis of soil type, variety, duration of growing period and target yield. The rates of nitrogen fertilizer vary from none on some rich lands to 200 kg N/ha on heavily exhausted soils. The nitrogen efficiency to produce extra yield declines with every increment in its dose. The first two-thirds of nitrogen application is three times more efficient in increasing crop yield than the last one third (Constable, 1988). Added nitrogen increases yield primarily by prolonging growth and increasing the numbers of boll set. It also has secondary effect of increasing boll weight (Gardner and Tucker, 1967; Gerik *et al.,* 1989; Bouqet *et al.*, 1993; Moore *et al.*, 1994). Although nitrogen promotes growth and yield; excessive nitrogen can create production problems that may reduce yield and quality (Constable, 1988, Silvertooth, 1993). The problems encountered with excessive nitrogen are rank growth, delayed maturity, difficult defoliation and poor insect control. Combining soil tests with petiole nitrate monitoring during the season can prevent excessive nitrogen fertilization. This technique consistently leads to good yields and maintained vegetative/reproductive balance of the crop.

Regardless of the level of nitrogen supply and/or crop boll load, a maximum nitrogen yield was reached at about 100 to 105 days after sowing (Crowther, 1934; Basinski *et al.*, 1975; Malik, 1976). The peak nitrogen demand develops during boll filling phase and could reach a level of 2 to 4 kg N/ha per day depending on yield potential (Constable, 1988; Hake, *et al.*, 1991). The time lag of about 3 weeks between the application of nitrogen and its use by the crop should be considered in timing applications. Adequate nitrogen should be available from squaring to boll burst to ensure optimum yields, hence the virtual universal recommendation of nitrogen applications at the flowering stage. Usually, some nitrogen fertilizer is applied at the time of planting to sustain early plant growth.

Single high rates of preplant nitrogen applied in fine textured soils are common practice for maximum yields while coarse textured soils benefit from multiple application. The split application of nitrogen, one quarter to one half at planting and the remainder at early to mid bloom is most common for many cotton growing regions, successfully producing top yields without delaying maturity. The sources of nitrogen are of no concern to farmer, the most important consideration being cost.

Placement of fertilizer in the soil depends on the source of nitrogen and soil conditions. In mechanised farming, nitrogen is often banded in the hill or side dressed and then incorporated. Peasants in Africa and Asia often broadcast nitrogen and then apply irrigation water to move and incorporate it in the soil. Recently, farmers have started water run fertilizer application to overcome logistic problems. This may lead to uneven distribution and poor crop response to nitrogen. In a comparative study on fertigation and soil applied nitrogen at the Cotton Research Institute, Multan, more nitrogen ($\geq$10 percent) was needed in fertigation for the same cotton yield. Nevertheless, fertigation is a useful method of countering deficiencies that are discovered too late in the season and to be corrected through soil applications.

Foliar application of nitrogen late in the season at the rate of 8 to 10 kg N/ha has been found useful in correcting nitrogen deficiencies and increasing seed cotton yield. Urea is a common source for foliar application and the risk of leaf burn can be reduced by late evening application. Experiments have shown heavier yields of cotton when foliar nitrogen is applied one day before irrigation in soils that are prone to temporary water logging after irrigation (Hodgson, 1982; Constable, 1988). Foliar nitrogen fertilizer can increase cotton yields where deficiencies occur, but the uptake from foliar applications is limited, so soil applications are necessary for severe deficiencies.

Since nitrogen is important for good yields, its application needs to be kept under strict control. The question of how much to add, when to add and where to add it depends on the soil and crop conditions and the ability of the manager to observe and judge them properly. It makes good sense to check the temperature, water status, insect pressure, soil and petiole tests and plant maps and add what is needed, it is needed.

Phosphorus

Phosphorus is a key element for cotton growth and yield. Phosphorus deficiency stunts plants and delays maturity. Cotton plants utilise about 7 to 10 kg of P_2O_5 per bale of lint. This correlates well with recommended fertilizer rates of 50 to 75 kg/ha. The uptake of phosphorus is very similar to nitrogen, paralleling dry matter production. Cotton seed is the highest reservoir containing about half the total plant phosphorus. Under conditions of low P, reproductive growth is limited more than vegetative growth. Little Phosphorus is translocated from vegetative organs to fruit (Nelsons, 1980), necessitating a continued P supply during all stages of growth.

Roots take up phosphorus as orthophosphates. Once applied to soil, phosphates fertilizers undergo reactions that transform the available phosphate to less soluble forms. Phosphorus is fixed by iron and aluminium in acidic soils and by calcium in alkaline soils so soil pH has a major effect on its availability. It is significant that phosphorus uptake decreased more in alkaline than acidic soil at equal concentrations (Black, 1968).

Phosphorus recovery is hardly 15 to 20 percent in the first year following fertilization. This is related to fixation and low mobility in soil (Salim *et al.*, 1986) Fertilizer phosphorus availability can be increased by mixing it with form yard manure (Sharif *et al.*, 1974 a, b; Malik *et al.*, 1990) and through band application (Silvertooth *et al.*, 1992; Hake *et al.*, 1991). At low soil test levels, phosphorus banding gives greater response per unit of fertilizer than broadcasting. Consequently, there are potential merits in applying phosphorus fertilizer in concentrated bands (Evans *et al.*, 1970; Funderberg, 1988). Broadcast applications of phosphate fertilizer are not recommended on acidic and calcareous soils but on neutral soils, particularly sandy soils, broadcast applications may be beneficial. Maintenance phosphorus applications can be broadcast on all soil types. In most cases banded application of phosphate are recommended to improve cotton production.

Phosphorus mobility is the prime limitation to its uptake by cotton plants (Khasawneh and Copeland, 1973). It does not move in soil water, so cotton roots must reach the phosphate ions for their utilization. Cotton roots are aided in intercepting soil phosphorus by mycorrhizal fungi, making cotton highly dependent on mycorrhizae for phosphorus uptake. Phosphorus deficiencies can be induced by eliminating these fungi. Long term fallow, over flooding and fumigation suppress mycorrhizal populations so grain crops prior to cotton would be preferable.

Soil pH influences the form of phosphate applied. Superphosphates and monoammonium phosphate are better suited to alkaline soils while diammonium phosphate is preferred for acidic soils (Papadopoulos, 1985; Holden and Constable, 1994, Malik *et al.* 1994). Phosphorus uptake is greater from the upper soil layer than from lower layers. Cotton roots located at 30 to 60 cm below soil surface are less effective per unit length than those located at 0 to 30 cm all else being equal. A significant decrease in phosphorus flux occurs when plants reach the flowering stage (Patrick *et al.*, 1959; Nayakekorala and Taylor, 1990). Clearly, the best time to apply phosphorus is preplant to allow time for it to become available. Delaying phosphorus application beyond pre bloom stage is unlikely to benefit the crop (Kasana and Ropal, 1980; Holden and Constable, 1994).

The prediction of cotton response to phosphorus is unreliable because its vigorous root system can mine soil up to 2 meter deep (Malik *et al.*, 1992) and because of residual phosphorus left by rotational crops. Phosphorus fertilizers applied to wheat, alfalfa and corn often carry over to cotton. Thus in most situations, the response of cotton phosphorus is erratic and unpredictable.

Soil tests could aid in deciding phosphorus rates for cotton. The indicative levels of soil phosphorus in deciding fertilization rates are presented in Table 5 (Hearn, 1981).

The calibration of a soil test with yield level is not available for cotton. It is suggested that for most crops in most conditions, a response will usually be obtained when a "low" test reading is indicated, will frequently be obtained with a 'moderate' level but only "rarely" with a "high" reading. In general soils having 12 ppm Olsen's phosphorus do not respond to fertilization (Halevy, 1979; Malik, 1995). Soils having high level of phosphorus should have strip trials to provide guidance for future phosphorus application. Plant tissue analysis does not help to correct phosphorus deficiency of growing crops but can be used to determine future fertilization programmes. Foliar sprays of phosphorus are not an effective way of delivering phosphorus to cotton.

Potassium

Potassium fertilizer use is increasing in cotton production world-wide. Potassium uptake of 125-145 kg K/ha is required by the cotton crop to produce a good yield. The plant consumes excessive K if the supply is over abundant. If the ratio of K consumption exceeds 0.13 kg of K per kg of lint, K has been over abundant, resulting in luxury consumption (Kerby and Adams, 1985). Potassium uptake by cotton in most cases equals or exceeds that of nitrogen. Therefore, to obtain optimum yield, potassium supply should be maintained throughout the season. Potassium requirements are moderate during early stages of cotton plant development but rise dramatically when bolls begin to develop. Bolls are major sinks for potassium and when many bolls are set rapidly, it can plummet before K fertilizer can be applied. The cotton crop may absorb 2 to 3 kg of potassium/ha/day during the peak demand period. This necessitates abundant K supply in soil during boll formation to cope with the high demand. High root densities and good moisture conditions can improve potassium uptake. In case of K deficiency, cotton plants redistribute K from leaves to bolls in time of high demand.

Soil analysis is a useful tool to determine yield responses to fertilizer potassium. Soil sampling for potassium should be from the top 30 cm. The present established sufficiency level is 120 to 150 ppm of ammonium extractable potassium. Soil clay mineralogy and variety grown may modify the yield response to potassium fertilization. The probability of increased yields at various soil test levels obtained at San Joaquin Valley, California is presented below in Table 6.

Potassium fertilizer rates are prescribed on the basis of potassium critical levels. Soils with 120-150 ppm available potassium do not need additional fertilization. The optimum rates recommended for various soils vary from 250 to 400 kg K_2O/ha. A maintenance dose of 100 kg K_2O/ha is recommended in non responsive soils to avoid expected deficiency (Weir *et al.*, 1997). Potassium in form of KCl or K_2SO_4 can either be broadcast or applied in bands, with no yield benefit of one over the other. However, roots do not actively grow towards potassium as they do towards phosphorus and nitrogen so potassium should preferably be applied in the same band as phosphorus or nitrogen for efficient utilization.

During the season, plant tissue tests can help detect potential potassium deficiency. The appropriate critical levels for petiole K during the peak demand period of cotton growth are provided in Table 7. In case of K deficiency during the season, foliar sprays of potassium nitrate at the rate of 4.6 kg K_2O/ha at 2 weeks interval over the fruiting period may help to alleviate shortages of K within the plant.

Premature leaf senescence late in the season occurs in cotton that is deficient is potassium. Symptoms are yellowing of leaf veins, followed by reddening and premature senescence. Short season varieties are more prone to K deficiency. Heavy fruiting on small plants and restricted root growth due to soil compaction and poor drainage aggravate the situation. Adequate N and K supply and deep ploughing can stimulate root growth and thus reduce K deficiency problems. Soil and crop management are the key to preventing this problem.

Sulphur

Sulphur is required by plants at about the same rate as phosphorus. A cotton crop removes 12-15 kg S/ha from soil during the season. Soils with less than 10 ppm sulphates were considered deficient. Sulphur deficiency is more likely in deep, sandy soils and those receiving high analysis fertilizers (Mascagni *et al.*, 1991; Malik and Makhdum, 1997). Sulphur is very mobile and leached from coarse textured soil. Cotton response to sulphur is higher when its roots are confined to the top 30 cm of soil.

Sulphur deficiency is usually corrected with applications of gypsum or elemental sulphur. The recommended range for sulphur fertilization in deficient soils is 7 to 20 kg S/ha (Mullins, 1996; Malik and Makhdum, 1997). Yield responses to sulphur are shown in Table 8.

Sulphur source and method of application did not affect yield. Sulphur is often applied preplant with NPK fertilizers. Leaf analysis can help to diagnose "S" deficiency. Sulphur level less than 0.2% in the leaves at flowering stage represent a deficiency level. Furthermore, a ratio of 20 or more of NO_3-N to SO_4-S represents sulphur deficiency in cotton crop. A foliar application of 4-kg SO_4-S per ha can help to overcome sulphur deficiency. Proteolysis hardly occurs during sulphur starvation of cotton plants so a continuous supply of external sulphur is desired for optimum yields.

Boron

Boron fertilization is not common in cotton. However the benefits from boron fertilization have been demonstrated in soil containing 0.2 to 0.5 ppm hot water soluble boron (Hinkle and Brown, 1968, Malik 1995a). The boron availability is low in sandy soil and highly acidic or alkaline soils that are low in organic matter. The recommended dose to overcome deficiency in these soil is 0.5 to 2 kg boron/ha at preplant stage with other fertilizers. Boron fertilization should only be attempted after careful assessment of risks and benefits, because toxicity could arise from excessive dose and water stress. Borax, B fortified superphosphate and various proprietary fertilizers are used to fertilize the crop. Boron is also foliar applied at the rate of 0.2 to 0.5 kg B per ha at flowering stage to correct deficiencies. Foliar application of boron has no advantage over soil application because of lack of translocation of foliar applied boron (Hearn, 1981). Leaf analysis can diagnose both deficiency and toxicity. Cotton shows deficiency when leaf boron drops to 15 ppm and toxicity when leaf boron approached 500 ppm. Toxicity symptoms include marginal leaf necrosis and cupping due to the accumulation of boron in leaf edges. In case of boron deficiency, the plants are stunted, flowers are deformed and leaves are irregular that are often buckled. Shedding of young fruit results in rank growth and low yield.

Zinc

Zinc is another important micronutrient likely to be deficient in cotton. Soil tests are recommended to evaluate fertility status of cotton fields. Soil are considered deficient when soil zinc drops below 0.5 ppm zinc based on DTPA extraction method (Brown *et al.*, 1978). Rates of 5 to 20 kg/ha of metallic zinc in form of zinc sulphate are recommended, depending on severity of deficiency and potential for zinc soil fixation. Calcareous, high pH or fine textured soils can severely inactivate zinc in soil. Liming and high phosphate levels many reduce zinc availability to cotton crops (Hinkle and Brown 1968). Analysis of fully expended leaves is often used to discover zinc deficiency. Cotton petioles or leaves are considered deficient when the tissue levels drops below 15 ppm zinc. Foliar application of 0.5% zinc sulphate is the preferred method to correct deficiencies discovered after planting. Multiple application of zinc spray may be necessary to overcome mobility problem in plants.

Other Elements

All essential elements are important to cotton growth and yield. However, responses to those not discussed individually are very rare and insignificant. Soil application of calcium and magnesium may be desired in specific cases. Foliar application of manganese, copper and iron could be useful in individual fields.

Long term sustainability of soil productivity

Long term sustainability of soil productivity can best be gauged from results of long term fertilizer experiments. Results from an experiment established in 1896 at Auburn, University, Alabama, USA showed that cotton does not excessively deplete the soil. Organic N systems (winter legume) and N fertilized systems have similar effects on cotton productivity. However, economics may not justify growing legumes simply for nitrogen fertilization of cotton (Mitchell *et al.*, 1991; Bauer *et al.*, 1993).

The timing of fertilizer P and K application had no effect on cotton yield once soil test values reached sufficiency level. Cotton yields in zero fertilizer system gradually declined over a period of 20 years and then stabilised at about half the beginning yield (Mitchell *et al.*, 1991; Mitchell, 1996). Results from long term fertilizer experiment at Multan, Pakistan corroborates the conclusions drawn at Alabama, USA. Cotton productivity was limited by nitrogen in wheat cotton-system but can thrive on residual P and K left over by wheat with no loss in yield. These data clearly demonstrate that fertilizers have no negative effects on soil and crop productivity and thus ensure viability of present farming systems.

Conclusion

The maintenance of all essential elements in the soil at sufficient level is fundamental to cotton growth and yield. However, that does not necessarily mean that all essential elements should be provided to cotton in fertilizer form. Fertilizer recommendations must be based on expected crop response to added nutrients. Soil tests and plant tissue analysis may help in making accurate fertilizer recommendations. Fertilizer programmes should envisage an integrated plant nutrition system approach to keep soil productive for sustained cotton yield.

An efficient fertilizer program should keep in mind the time when various nutrients are needed by the crop and the fate of nutrients applied to soil. The demand for nitrogen is greatest during boll filling phase but carry over into harvest is detrimental. Phosphorus is needed throughout the season but its availability is limited by root development and soil fixation. Potassium is needed in moderate amount early in the season but its demand increases dramatically during the boll filling phase.

Phosphorus and potassium immobility and nitrogen vulnerability in soil pose problem in time and method of application. Pest management, water supply and variety all interact with crop response to nutrients and need consideration while devising a viable fertilizer programme. Putting the information and technology that is at hand to work can lead to a more efficient scheme for soil and plant nutrition programmes for cotton. There is a continuous need to understand farming system of which cotton is a component and to manage fertilizer to any given crop for highest possible efficiency.

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Table 1. Fertilizer contribution to seed cotton yield increase.

Type of Agriculture	Seed cotton yield (kg/ha) Without fertilizer	With fertilizer	Increase %
Rainfed	578	902	56
Irrigated	1860	3764	102

Table 2. Chemical composition of cotton plant at maturity.

Plant Parts	Concentration Percent					
	N	P	K	Ca	Mg	S
Roots	0.82	0.11	1.06	0.32	0.25	0.06
Stalks	1.06	0.17	1.60	0.55	0.17	0.06
Leaves	2.30	0.21	2.63	3.15	0.56	0.48
Capsules	1.80	0.16	3.30	0.36	0.33	0.14
Seeds	2.75	0.43	0.98	0.33	0.48	0.05
Lint	0.13	0.04	0.39	0.06	0.07	0.04

Table 3. Nutrient uptake based on yield level of one tonne of lint/ha at Multan.

Nutrients	Unit	Non-Harvestable	Harvestable	
		Capsules+Leaves+Stalks	Seed	Lint
Nitrogen	kg	130	71	2
Potassium	kg	105	21	5
Phosphorus	kg	20	12	3
Calcium	kg	56	2	0.4
Magnesium	kg	22	3	0.6
Sulphur	kg	17	2	0.4
Zinc	gm	64	24	Trace
Copper	gm	30	9	Trace
Boron	gm	1.7	23	Trace
Iron	gm	826	115	Trace

Source: Malik (1995a)

Table 4. General fertilizer recommendation kg/ha.

Country	N	P_2O_5	K_20	% of Total Fertilizer Used on Cotton
Australia	135	10	0	2.25
Brazil	28	48	48	0.25
China	120	70	25	3.00
Egypt	66	23	24	3.00
India	40	20	20	4.84
Israel	200	120	100	5.76
Mexico	176	28	0	4.74
Pakistan	120	50	25	16.20
South Africa	100	46	18	1.00
Turkey	150	160	10	7.28
USA	108	48	57	5.70
Uzbekistan	110	25	0	42.60

Source: ICAC (1996); FAO, IFA, IFDC (1996)

Table 5. Soil phosphorus levels (ppm).

Extractant	0.05 HCl	0.05 $MNaHCO_3$
Low	0 -.16	0.- 5
Moderate	17 - 37	6 - 10
High	> 38	> 10

Table 6. Soil critical K level and probability of increase in yield.

K level (ppm)	Yield increase kg /ha.	Probability
< 70	220	> 80
70-90	120	80-60
90-110	105	60-40
110-120	60	40-20
> 120	< 35	< 20

Table 7. Petiole critical K levels.

Growth stage	Very low	Low	Medium	High	Very high
1st flower	<2.5	2.5-3.0	3.0-3.5	3.5-4.0	> 4.0
Peak flowering	<1.8	1.8-2.4	2.4-2.8	2.8-3.2	> 3.2
Cut out	<1.0	1.0-1.4	1.4-1.8	1.8-2.4	> 2.4

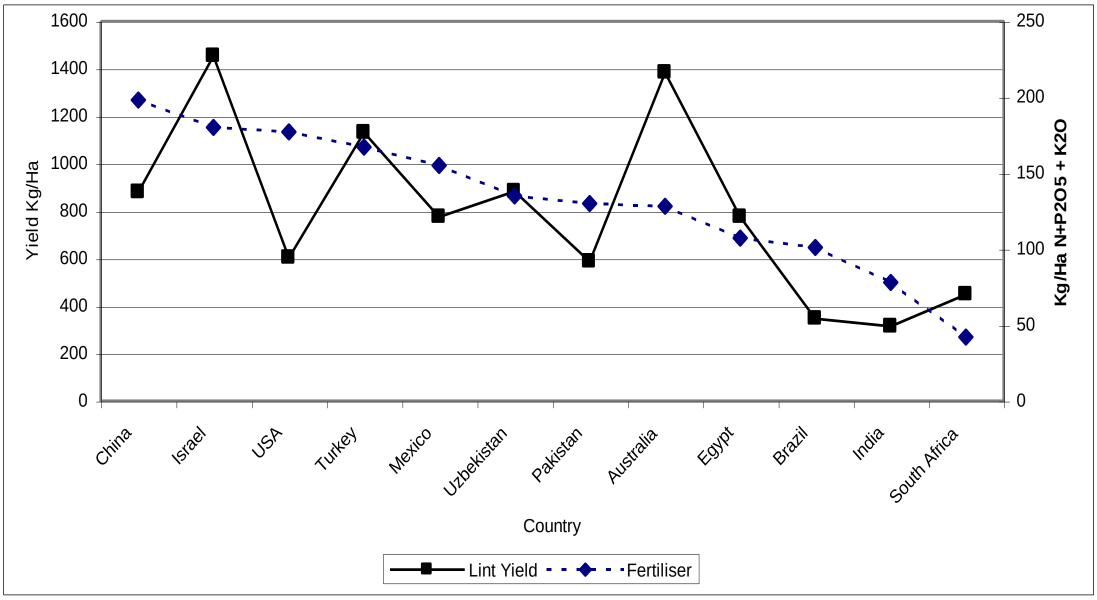
Table 8. Cotton response to sulphur fertilization.

Region	Sulphur Dose (kg ha^{-1})	Seedcotton Yield (kg ha^{-1})
Pakistan	Check	2095_a
	7	2242_b
	14	2255_b
	28	2257_b
USA	Check	1215_a
	10	1401_b
	20	1526_b
	40	1480_b

Table 9. Ten years average crop yield 1986-1995.

Treatments	Seed cotton (kg/ha)
No nitrogen	930 a
Legume N: 116 kg/ha	2230 b
Fertilizer N: 120 kg/ha	1860 c

Figure 1. Nutrient use and yield of lint by country.



Source: FAO, IFA, IFDC, ESS?MISC?1996/3, USDA FCI-97(1997)

Figure 2. Plant nutrient removal per tonne of economic yield in different crops.