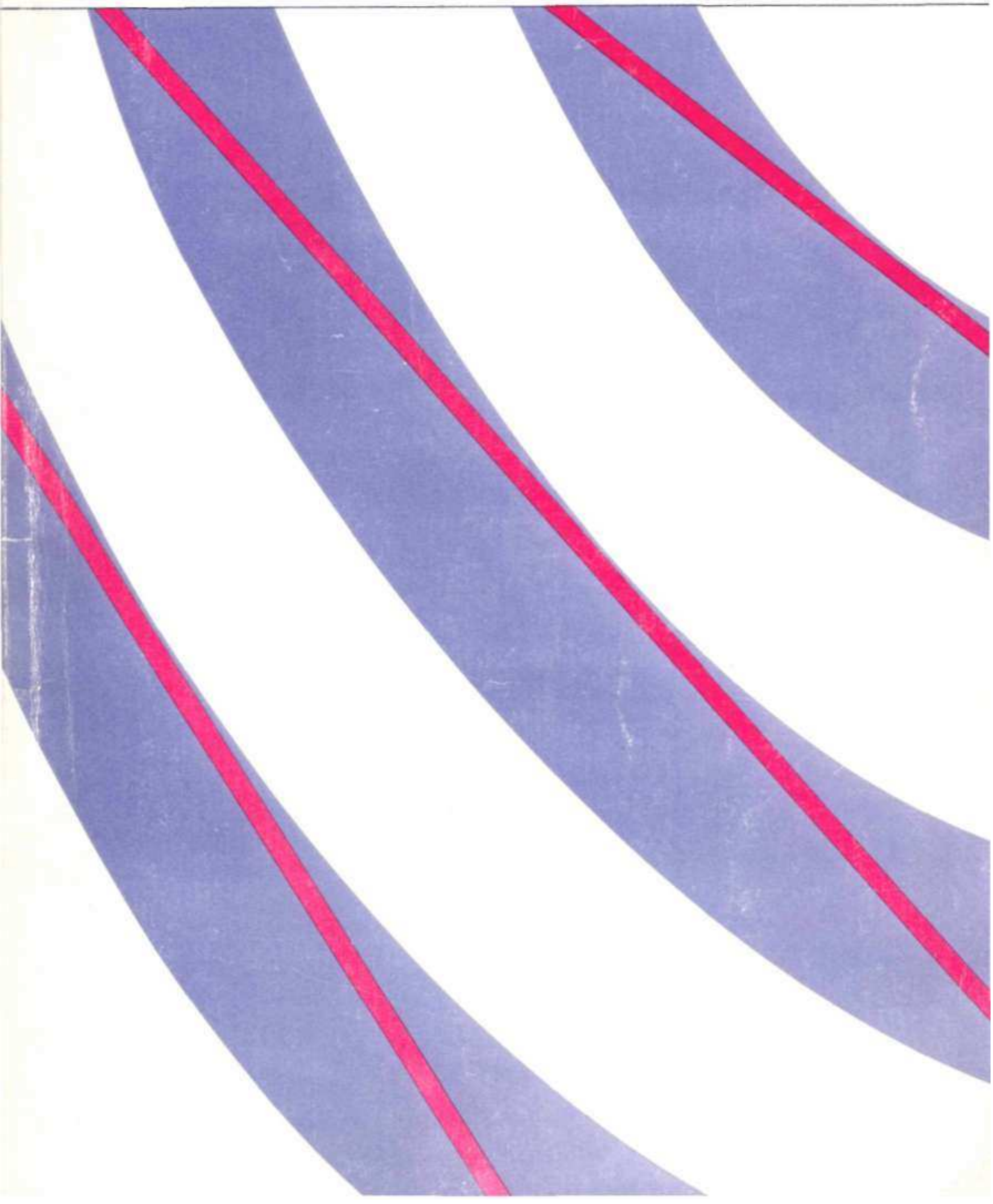
THE ECONOMICS OF TRACTORS IN SOUTH ASIA

AN ANALYTICAL REVIEW BY HANS P. BINSWANGER



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CONTENTS

I. / INTRODUCTION

TRACTORIZATION of agriculture in low-wage countries has been the center of one of the most virulent and emotional choice-of-techniques debate for the past 20 years. It is therefore not surprising that, apart from spawning large quantities of theoretical-conceptual literature and a massive amount of partisan writing, it has also led to a very substantial amount of careful empirical work at the micro- and macro levels. In particular, there are now available a large number of farm-level tractor surveys from practically every agroclimatic zone in the Indian subcontinent. However, many of these surveys are not easily accessible (masters and Ph.D. theses) or not easily comparable. The main effort of this paper is to assemble the studies and present their findings in a way which makes them comparable across agroclimatic zones. Whatever merit this summary may have thus goes in large part to the patient (and sometimes unrewarding) effort of the many researchers who assembled the basic facts initially. Of course, they cannot be held responsible for mistakes or misinterpretations which might have occurred in the summarization process.

It should be clearly noted at the outset that conclusions reached in this paper *are conditional to the agroeconomic environment which is studied.* What we observe on farms in the Punjab is caused by the agroclimate, the availability of land and irrigation, the farm sizes, and the factor prices. *In a different environment*—such as Africa—*the introduction of tractors must be expected to lead to different results.* Conclusions from South Asia are thus only transferable to those developing regions which have similar agronomic and economic environments.

II./SUBSTITUTION VERSUS NET CONTRIBUTION

THE debate about the benefits of tractors has essentially been between two apparently contradictory views:

The *Substitution view* looks at tractors and animals as two different power sources which technically are perfect substitutes, i.e. any operation which a tractor with its implements can perform is assumed to be also feasible by a combination of animal power, animal-drawn implements, and hand labor. Under this view the switch from animal power to tractor power[1] is primarily guided by factor prices (or factor scarcities).

If the opportunity cost of labor (measured either by wage rates or by man/land ratios) and the cost of maintaining bullocks become sufficiently high, it will make sense to shift to tractors. As long as income-distribution implications are neglected, this would be the case both from the individual and societal points of view. Under the substitution view, the low labor costs in the subcontinent are often taken *as prima facie* evidence that the time for a switch to tractors has not yet come. It should be noted, however, that under the substitution view the question of tractors is primarily an issue of appropriate timing of the tractor investment. This view is entirely consistent with advocating tractors at a future date in the subcontinent when wage rates rise to higher levels, or in other regions of the developing world where high wage rates and/or an open land frontier alter costs in favor of tractors.

The *Net Contributor view* of tractors, in its more extreme forms,[2]

'We will neglect the issue of switch from hand labor directly to tractors. Only in a few mountain areas is primary cultivation still done by hand labor in the subcontinent.

See for example, G. W. Giles 1969, and Roger Lawrence 1970 in the context of Pakistan. The Pakistan debate has been particularly intensive with S. R. Bose and E. H. Clarke II (1969), J. Cownie, B. F. Johnson and Bart Duff (1970) arguing against the argues that power is a primary constraint to agricultural production almost regardless of factor prices. The greater power of tractors allows more thorough or deeper tillage than with bullocks. Tractor machinery such as seeders, levellers, and interculture equipment also achieve a higher level of precision. Both factors would lead to higher yields. Furthermore, tractors may be able to reclaim land which cannot be operated by bullocks at all. Finally, the higher power and speed of tractors would allow more timely operations, thus contributing both to higher yields and to a more extensive practice of double cropping. Higher yields and double cropping would lead to higher levels of output, requiring more labor in operations not performed by the tractor. The tractor could therefore contribute to increased production without necessarily displacing labor. Tractorization would be consistent with employment objectives, even in low-wage countries.

The two positions are deliberately described in their extreme form. However, it is necessary to emphasize that the views, when properly specified, may not be all that contradictory. The points of agreement and disagreement between the views may best be illustrated with the following example.

Suppose that, in an irrigated area, wage rates and bullock costs are so low that it is economical to maintain a very large labor force and bullock capacity which will allow double cropping with timely operations.[3] If the substitution view is correct, it may be quite some time after bullock costs and wage rates start to rise before tractors become the least-cost technique of production. At constant output prices the sole effect of increases in wage and bullock costs is an increase in production costs, thus making farming less profitable. Farmers will attempt to reduce costs by reducing input and output levels, which may partly be in the form of decreases in the labor force and bullock stock. Profitability of the second season crop may be affected first and its extent reduced, thus reducing cropping intensity. The quality of other mechanical operations may also deteriorate. As labor and bullock prices continue to rise, tractors will eventually become profitable and be substituted for bullocks and for labor, thus making production costs less vulnerable to further wage and bullock cost increases.

If, for some reason, tractor investments were restricted at that stage, farmers would react to additional wage and bullock cost

views of Giles and Lawrence. The Pakistan debate has largely been resolved by the studies of Carl Gotch, Bashir Ahmad, Walter P. Falcon, Muhammad Nasim and Shahid Yusuf (1975). G. W. Giles (1975) expresses the net contributor view in a less extreme form. In India the net contributor view was forcefully expressed by S. S. Johl, 1973.

'Many areas in Japan and Taiwan achieved double-or triple-cropping long before the advent of tractors. In Bihar, for example, some bullock farms operate at a 200% cropping intensity (Table 8).

increases by further reducing their labor and bullock input; the quality of mechanical operations and intensity levels might fall further. Introduction of tractors at this point may provide substantial cost reductions which (still at constant output prices) would make farming more profitable, thus leading to a positive intensity and output response. This more sophisticated *substitution view,* which takes into account the output effect of cost changes, thus agrees with the net contributor view that production effects are possible; but it would insist that such productivity responses to tractors, at the farmers' level, are only possible if the tractor does indeed reduce production costs.

This more sophisticated substitution view would therefore argue that tractors can be an important engine of growth, *provided that animal power costs and wage rates are ruing.*[4] Since cost differences between techniques need not be large to induce a switch to tractors, one would not expect large output responses at the switchover stage. Only modest timeliness and intensity gains might be observed at that stage. However, bullock and labor use reductions would have to be observable, since these cost components need to compensate for the added capital costs of tractors. If this view is correct, we would expect to *observe large output and intensity gains from adoption of tractors only if tractor investment had somehow been retarded long past the stage when it initially gained a cost advantage.*

Thus, the net contributor theory also fits into our example, and is not as inconsistent with the substitution view as initially implied. The net contributor view would argue that, in our simple example, we are long past those bullock and labor cost situations which would permit the high timeliness and intensity levels assumed in the initial situation, and that the costs of animal power and labor so much reduce the profitability of farming that it does not pay to practice the higher work quality and intensity levels with the traditional methods.[5] If we were to place our example in a situation with little irrigation, the contributor view might argue that the cost of animal power is so high that it makes investment into complementary irrigation unprofitable, while tractors could sufficiently reduce costs to make the complementary irrigation investments profitable.

The issues are empirical rather than theoretical. The plan of this

[4]The tractorization of American agriculture is a good example. In the absence of labor-saving innovation, U.S. agriculture could never have remained an important exporter of agricultural commodities. The wage-rate rises would have resulted in a loss of comparative advantage of U.S. agriculture on a cost basis.

'Alternatively, the net contributor view would have to deny the perfect technical substitutability of bullock- and tractor-powered operations. In view of the historical experience of Japan and Taiwan, where high yield and intensity levels were achieved long before tractorization, this position is untenable.

paper is thus to review and compare, in Section III, the tractor surveys of other authors to see if we observe the high yield and intensity gains and the lack, or even increase, in labor use which would vindicate the net contributor view. In Section IV, some of the major benefit-cost studies are reviewed to see if tractors lead to substantial cost reductions.

III./THE TRACTOR SURVEYS

BEFORE turning to the evidence it is necessary to review in some detail a few major methodological issues connected with tractor surveys.

Methodological Considerations

The methodology most often used in tractor surveys has been the *cross-section comparison* of various types of bullock-operated farms with various types of tractor-operated farms *at a given moment of time.* Other researchers compiled data for tractor farms only, and judged the impact of tractorization on the basis of *before* and *after* comparisons—with the *before* data inevitably collected on a recall basis (Mclnerney and Donaldson, Chopra, Sapre). Pudasaini collected data both cross sectionally and *before* and *after.* Even in his study, however, *before* and *after* data for the bullock-operated farms are missing.[6] It is clear that a full combination of both approaches would be most powerful, and it is difficult to understand why so few studies have collected *before* information for at least the more easily recalled variables, such as farm size and cropping patterns.

The key objection raised against pure cross-sectional comparison is that tractor and bullock farms differ in many other respects in addition to power source. Tractor farms usually are larger than nontractor farms. Farmers who own tractors can generally be expected to be better endowed with productive capital and to have a better access to credit markets. This is likely to lead to greater per-hectare use of irrigation and purchased inputs, and thus to higher observed yields and cropping intensities. Furthermore, tractor-owning farmers might choose cropping patterns which emphasize crops with high returns but which require relatively large

[6] Desai and Gopinath present some *before* and *after* farm-size comparisons.

amounts of purchased inputs. These effects could lead to higher production, higher yield, higher intensity, and higher labor input regardless of the prime source of power—bullock or tractor—employed.

Most investigators have obviously been conscious of these confounding factors, and many have attempted to minimize them by judicious choice of sample farms. Some investigators have chosen *size-adjusted* samples by excluding the smallest bullock farms and sometimes the largest tractor farms from their samples[7] (Kahlon 1975, 1976, Government of Punjab, R. K. Sharma, Grewal and Kahlon, Motilal, Misra). This has, however, been difficult in areas where tractor density is still low.

The Punjab (India) and Haryana (Tables 2, 3, and 4) studies, as well as some others, have encountered few problems of confounding with irrigation because tractor- and bullock-operated farms had essentially equal access to irrigation (Kahlon 1975, 1976, Government of Punjab, Sharma, Motilal, Chandra Mouli, Umakesan, Mandal and Prasad, Parthasarathy and Abraham). Other studies, attempting to overcome the irrigation problem by the sampling design, have distinguished farms with pumpsets or tube-wells from those farms without and separate each farm class into tractor- or bullock-operated farms (Pudasaini, Singh and Miglani, NCAER 1973, Patel and Patel). This leaves only a few studies where irrigation remains an important confounding factor (the Gujarat Studies (Table 6), Singh and Singh, Narayana, Pawar and Acharya).[8]

The sampling process could not adjust for differences in the use of high-yielding varieties, fertilizers, or pesticides. However, most writers have been careful in documenting these differences. It turns out that in some areas the use of HYVs is not correlated with tractor use. In particular, there is little difference in HYV use in the later studies of the Punjab, *thus contradicting the hypothesis that HYV use and tractors are necessarily complementary,* i.e. that there is a strong positive interaction from their joint use (Government of Punjab, Kahlon 1976, Singh and Miglani). In the rice-growing areas of coastal Andhra Pradesh and in Bihar, however, the use of HYV rice seems to be more closely associated with tractor ownership.

[7]In view of the negative correlation between farm size and output per ha (observed in certain areas of the subcontinent), a sampling design which adjusts for farm size seems to be very important.

[8]Soil differences between the farms should not lead to much confounding. The studies have generally selected villages which have a fairly large number of tractors, and selected a matching number of tractor-operated and bullock-operated farms within each village, thus eliminating most systematic soil differences.

Fertilizers probably present the most severe confounding problem. In extreme cases, tractor-owning farmers used up to 12 times the rate of fertilizers used on pure bullock-operated farms (Pudasaini); in most instances tractor-operated farms used between 20 to 60 percent more fertilizer per unit area. In comparing yields or total production levels, caution must therefore be exercised. The best procedure is probably the use of covariance analysis to remove the effect of fertilizer (Kahlon 1975), or of fertilizer and other confounding factors combined (Desai and Gopinath).

One confounding factor which has received little attention is the quality of management of the farm. If tractor owners belong to a more educated group than do bullock farmers, they should achieve higher levels of productivity from any given resource base, with or without tractors. Unfortunately, only three of the studies present data on this aspect, and they all report higher levels of formal education for tractor farmers than for bullock farmers.[9]

Most of the confounding effects can be expected to exaggerate the advantages of tractors. In areas such as the Punjab where a negative correlation may exist between farm size and farming intensity, farm size could work in the opposite sense.[10] But this opposite factor can operate only in those smaller studies *which do not use a size adjusted sampling frame.* With this exception, we therefore must expect cross sectional studies to exaggerate the benefits of tractorization. Unfortunately this advantage is not easily quantifiable.

It might appear at first that *before* and *after* studies overcome most of these confounding effects. However, this is not always the case. One problem is that the *before* data must often be collected with 3 or 4 years of recall, which may be less reliable.

Clearly, the *before* and *after* studies do not suffer from confounding due to management bias. However, confounding due to irrigation, HYV, and fertilizer use still remain. The Mclnerney and Donaldson study in Pakistan is a striking example. Farms which acquired tractors grew, on average, to two and one-half times their former size. This represents formidable problems of interpretation,

[9]Parthasarathy and Abraham report a significant correlation between literacy and tractor use (but not with age or tenancy). The Desai-Gopinath study allows the construction of a schooling index of different types of farmers which, in two areas, shows tractor owners to have about 20 to 30% more years of schooling than bullock farmers, with no difference in the third area (Table 5, Desai and Gopinath). A much larger educational advantage, where two classes of tractor owners have twice as many years of education than do the bullock farmers, is reported by Pudasaini. Note that none of the studies reports extension contacts by farm class. Given the *size* and educational advantage of farmers owning tractors, it is likely that they also have more frequent extension contacts.

[10]For a review of the farm size-farming intensity controversy, see Bharadwaj Krishna.

because it is not known to what extent that growth was caused by tractors. The Green Revolution and fundamental changes in price relationships occurred in the same interval; both may have contributed to the incentive for farm expansion, in addition to introducing other confounding elements. It is therefore clear that *before* and *after* studies should include a control group of farms of similar initial size to gain a real superiority over cross sectional studies.[11]

Another methodological advance which has occurred over time is statistical testing. Motilal's 1968-69 study first tested differences between farm types rigorously. We shall see that in many cases only fairly large differences are statistically significant. It is unfortunate that even in the late 1970's some studies do not report significance tests.

Over time there has been considerable refinement in distinguishing farm types. Early studies looked only at bullock owners and tractor owners (Grewal and Kahlon, Government of Punjab, R. K. Sharma, Singh and Singh, Motilal, Umakesan). After 1970, many studies introduce tractor-hiring farms as a separate category (Kahlon 1975, 1976, Pudasaini, Desai and Gopinath, Sharan et al., Mandal and Prasad, Parthasarathy and Abraham, Acharya, Narayana). As mentioned earlier, others distinguish according to ownership of pumpsets and tubewells. Also the Kahlon (1975, 1976) study distinguishes pure tractor farms from farms which continue owning bullocks in addition to the tractor. A minimal framework of data collection and analysis for future work in this area is given in Appendix A.

A Brief Overview of the Evidence

Table 1 presents a very brief initial summary of the evidence of all studies for which the details are reported in Tables 2 to 9. For the key performance measures, Table 1 classifies the differences between bullock-and tractor-operated farms (hired or owned) into five size groups and reports the frequency *of observations* in each of these size groups. Note that each *observation* is a comparison between a sample of tractor and a sample of bullock farms reported by the authors of the studies reviewed. For example, the entry in the *intensity* row and the "-30 to -10" column is 3.2. That means that in 3.2 percent of the 63 intensity comparisons reported, the intensity on tractor farms was

[10]Mclnerney and Donaldson tried to do so, but encountered problems because of an extremely restrictive definition of control farms—i.e. as those farms which applied for tractor loans but could not obtain a tractor. A more liberal definition of farms of similar size, regardless of tractor purchase intensions would, *ex post,* have been more appropriate.

TABLE 1. Distribution of differences between bullock and four-wheel tractor farms.

Percent Difference	No. of observations	Less than -30	-30 to -10	-10 to + 10	10 to 30	Greater than + 30
		Percent of observations				
Intensity	63	0	3.2	73.0	20.6	3.20
Individual crop yields	107	0.9	7.5	39.30	37.4	14.90
Total crop Production	45	0	2.2	20.0	46.7	31.10
Fertilizers etc.[a]	36	2.8	2.8	16.6	25.0	52.8
Labor	58	5.20	24.2	51.70	17.2	1.70
Labor/Unit of total Production	49	32.70	42.8	24.50		

"Sometimes includes seeds, manures, and pesticides.

"Sometimes includes seeds, manures, and pesticides.

lower than on bullock farms by between 10 to 30 percent. Only results of four-wheel tractors are summarized in Table 1.

For intensity of cropping, we see that 73 percent of observations fall into the "no clear difference" class of minus to plus 10 percent.[12] In almost 20 percent of the cases, tractor farm intensities are higher by 10 to 30 percent. There may therefore be some intensity advantage, but it is not impressive, and detailed examination of Tables 2 to 9 will be needed to see if the modest differences are indeed due to tractors.

Yield advantages seem at first to be more impressive. Of 107 comparisons, more than 50 percent of the differences exceed 10 percent; in 15 percent of observations the yield advantage exceeds 30 percent. Consider, however, that in about one-half of the reported cases fertilizer use on tractor farms exceeds that on bullock farms by 30 percent or more. This implies that the yield differences are clearly not caused by the tractor alone, and we must again look more carefully at the individual studies.

Total crop production per hectare is defined as the gross value of crop output divided by operated or net cropped area. In more than three-fourths of the cases it is larger on tractor farms by more than 10 percent and the differences exceed 30 percent in almost one-third of

[12] Of these, 28.3% fall into the 0 to -10% range while 46.3% fall into the 0 to +10% range—i.e., more are positive than negative.

the reported cases. We shall see that this impressive advantage is again caused by a variety of factors and particular attention will be given to cropping pattern effects of tractors.

The two extreme ways of looking at labor effects are both reported in Table 1. The extreme net contributor view would attribute all differences between farm types in total production per hectar to the tractor, and not to additional inputs such as fertilizers. It is assumed that if tractor farms were forced to go back to bullock and labor operations, production per hectar would revert back to that of bullock farms and so would labor use per hectare and bullock use.[13]

If this were true, observed differences in labor use per hectare would then correctly measure the labor effects of tractors. We see from Table 1 that the increases and decreases in labor per hectare are fairly symmetrically distributed around zero, with 51.7 percent of the reported cases not distinguishable from zero. Thus if the net contributor view were right, tractors would not be labor displacing.

On the other hand, under an extreme substitution view, taking tractors away from tractor farms would not necessarily result in a decline in production per hectare. Tractor farmers, if deprived on the tractor, would try to maintain part of their earlier production level by maintaining the use of fertilizer and other cash inputs close to the levels achieved when they had tractors. They would also have to buy bullocks and hire bullock drivers. Since production is maintained close to the level achieved with the tractor, labor for all operations not performed by the tractor would stay the same and the additional bullock drivers would be a net addition to labor use. Thus labor use would increase beyond the level required to produce the output of the pure bullock farms which never had a tractor. An *upper bound* on the labor effect of tractors can be found by looking at labor per unit of production rather than labor per hectare. This is only an upper bound because increases in production per hectare are ofter achieved by increasing labor (or bullock use) by a lower proportion than output is increased. For example, more intensive fertilizer use is likely to increase production by a larger proportion than will more intensive labor use.[14]

[13]The net contributor view would, of course, have to argue that the complementarities between tractors and other inputs such as fertilizers are such that, deprived of tractors, the tractor farmers would have to give up the use of these other inputs. For some inputs such as fertilizers, this view is almost absurd.

[14]For example, if a bullock farm suddenly uses more fertilizer, output per ha increases by a proportion k. This would require an increase in harvesting and processing labor by the same proportion k, *thus increasing labor per ha.* However, field preparation and seeding labor would remain constant, while weed control labor would probably rise by a proportion which must be less than k. Overall labor per ha thus

Differences in labor per unit of production can be computed approximately from many studies by subtracting from differences in labor per hectare the difference in production per hectare.[15] Results are not reported in the detailed tables, but are summarized in Table 1.

It is clear that tractor farms have much lower labor input per unit of output and measured this way *labor displacement* seems to be very large. We must note that, this is an *upper bound* on the labor displacement, even under a pure substitution view. Furthermore, if tractor farms generally use more threshers or alternative labor-saving equipments, the reduction in labor per unit of output could have been generated by these other innovations. The truth must therefore be *somewhere between what labor per hectare tells us and what labor per unit of production reflects.*

The Organization of Tables 2 to 9

To distinguish the farm types we will use the following symbols:

B Bullock farms
TO Tractor-owning farms
TH Tractor-hiring and custom farms
P Pumpset- or tubewell-owning farms
C Canal-irrigated farms
TR Thresher-owning frms

The most important combinations of the above are:

BP Bullock farm with pumpset
TOP Tractor-owning farm with pumpsct
THP Tractor-hiring farm with pumpsct
TOB Tractor and bullock owner

Note that in studies which do not differentiate according to irrigation source, B will stand for all bullock operated farms, regardless of whether they do or do not own pumpsets. Similarly, TH and TO include all tractor hiring farms and all tractor-owning farms regardless of pump ownership. Further, note that in some areas B

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rises by a proportion which must be less than k. Since output per ha rises by k and labor per ha by less than k, labor per unit of output musl actually fall. The observed difference in labor per unit of output therefore consists of a reduction caused by the tractor and a reduction caused by the fertilizer. Therefore, the observed difference overestimates the tractor effect and is clearly an upper bound.

[15]To see this, write $\frac{L}{A} = \frac{L}{A}/\frac{Q}{A}$. It can be easily proved that $\frac{d\,(L/Q)}{(L/Q)} = \frac{d\,(L/A)}{(L/A)} - \frac{d\,(Q/A)}{(Q/A)}$ and subtracting percentage changes is an approximation to the above formula.

Table 2. Results of tractor surveys for Punjab (India) and Haryana.

Author Area	Sample size Study year (1)	Comparison (2)	Labor days (days/ha) (3)	Bullocks/ha (4)	Intensity (5)	Value of gross output (Rs/ha) (6)	Yield (7) Wheat	Yield (7) Paddy	Inputs (8) Fertilizer	Inputs (8) Irrigation
Government of Punjab (India)	320									
All Punjab	1969-79 to	B	(84.1)	(21.4)	(138.23)	(2125)			(Rs.143.5)	(Rs. 109)
	1972-73	B-TO	−8.9	−75.4	7.0	14.3			38.3	−11.5
										Land revenue (Rs. 7.36) 11.4
Grewal and	300									
Kahlon Punjab (India Central and Southwest)	1969-70	B	(112.5)		(143.0)	(1687)				
		B-TO	+2.4		12.1	31.4				
Singh and Miglani	144									
Ferozepur dist., Punjab (India)	1973-74	BP-TOP	−20.6	−94.8						
		BC-TOP	−29.4	72.7						
Sharma,	80									Irrigation
Karnal, Haryana.	1970-71	B	(91.73)	(20.6)	(168)	(2677)	(25.49)	(26.49)	(Rs. 246)	(Rs. 149)
		B-TO	−0.0	−68.2		17.4	7.2	13.3	44.4	26.0
	Small	B-TO			5.7					
	Medium	B-TO			6.6					
	Large	B-TO			4.3					

TABLE—2

Notes on (Government of Punjab (India)

There are no large differences in irrigation between farm classes. Farm sizes are also fairly well adjusted between classes.

(3) Per ha cropped, Table 4.9
(4) Per ha cropped, Table 4.10b
(5) Table 2.13
(6) Per ha operated, Table 4.4
(8) Expenditure per ha operated, Table 4.2

Notes on S. S. Grewal and A. S. Kahlon

Analysis based on farms of matching size.

3) Man-days per ha of cultivated area. Table III.
5) Page 218
5) Page 218

Notes on A. J. Singh & S. S. Miglani

Sample not farm-size adjusted. Labor and bullock use given in energy terms, therefore only the percent change is of interest. The BP-TOP comparison refers to farms with irrigation mostly from tubewells while the BC-TOC comparison refers to farms relying mainly on canal irrigation.

3) Human energy requirement per ha of cropped area, Table 2.
4) Bullock energy requirement per ha of cropped area, Table 2.

Notes on R.K. Sharma

Sample is farm-size adjusted.

3) Table 4.2, days per ha of gross cropped area.
4) Table 3.6, excludes bullock use for transport to and from field; bullock days per ha of gross cropped area.
5) Table 2.2, absolute intensity is a simple average of the three size groups.
6) Table 2.5, value of gross crop output per ha of cultivated area.
7) Table 2.5.
8) Table 5.1, fertilizer and manures, irrigation expenditure per cultivated ha.

Table 3. Results of tractor surveys for Punjab (India) by A. S. Kahlon.

Study Area	Sample size Study year (1)	Com-parison (2)	Labor (days/ha) (3)	Bullocks (no/ha) (4)	Intensity (5)	Value of gross output (Rs/ha) (6)	Yield (q/ha) (7) Wheat HYV	Paddy HYV	
Overall Punjab	272	B	(59.3)	(18.9)	(158.7)	(3620)	(21.9)	(45.3)	
	1973–74	B-TH	4.3}	−22.6	−8.1	20.4}	21.2	5.3	
		B-TO	−1.1}NS	−100.0	12.0	57.8}NS	20.4	4.9	
		B-TOB	−5.6}	−68.3	−2.2	18.5}	18.7	2.3	
Region 1	52	B	(66)	(28.3)	(151.6)	(3283)	(24.6)	(42.9)	Maize (13.22)
Central Plains		B-TH	−6.1}	−19.8	9.2}	7.1}	5.7}	—	−14.22}
Maize Area		B-TO	−22.6}NS	−100.0	10.4}NS	31.9}*	1.1}NS	1.09	11.4}*
		B-TOB	−11.9}	−80.5	6.2}	29.0}	25.3}		20.8}
Region 2	52	B	(59)	(10.0)	(166.3)	(4681)	(27.2)	(50.9)	Ground-nuts (14.80)
Central Plains		B-TH	13.4}	−15.3	4.4}	28.9}	5.0}	17.8} NS	—
Maize-Groundnut		B-TO	24.4}NS	−100.0	7.7}*	94.0}*	10.2}*	19.8}	2.2NS
		B-TOB	−0.5}	−75.2	−0.3}	11.0}	10.0}	na	
Region 3	48	B	(57)	(17.4)	(170.6)	(3899)	(22.02)	(48.5)	
Central Plains		B-TH	6.0}	21.1	3.5}	7.0}	11.4}	−13.5}	
Paddy		B-TO	−21.8}NS	−100.0	6.6}NS	4.7}NS	27.1}*	na}NS	
		B-TOB	11.8}	60.5	0.7}	3.3}	3.4}	−0.5}	
Region 4	56	B	(59.9)	(20.7)	(174.5)	(3749)	(20.50)	(39.8)	Maize (18.03)
Semi-Hills		B-TH	8.3}	−21.1	−0.1}	27.8}	21.7}	27.6}	−3.3}
Maize-Paddy		B-TO	2.6}NS	−100.0	−1.4}NS	31.0}*	17.4}NS	2.3}NS	4.7}NS
		B-TOB	2.8}	−79.9	5.5}	24.5}	8.0}	9.1}	2.7}
Region 5	64	B	(57)	(16.2)	(144.6)	(3380)	(18.73)	na	Cotton (10.72)
South West		B-TH	−1.1} NS	−13.5	−26.9}	16.4} NS	44.2}		49.9}
Cotton		B-TOB	−2.0}	−54.0	−10.7}*	18.1}	33.7}*		31.3}*

TABLE—3

Notes on A. S. Kahlon (1975)

Farms are fairly well size- and irrigation-adjusted. The significance test indicated by asterisks* and NS test all three differences (B-TH, B-TO, and B-TOB) simultaneously. Results reported pertain mainly to 1973/74.

3) Per cropped hectare, Tables 8.2, 8.3, 8 hr = 1 day.
4) 8 hr = 1 day, Table 8.8, 8.9.
5) Table 3.9. If Region 5 left out, average crop intensity over region 1 to 4 increase in each tractor class. Intensity is significantly negatively correlated with farm size only in region 4 (Table 3.11). Cropping intensity not related tractor horse power (Table 3.14).
6) Gross output per ha. of operational holding. Table 5.2. Text and table disagree on whether differences in region 4 significant.
7) *Wheat, Table 4.7.* If yields adjusted by covariance analysis for fertilizer use, only region 5 remains significant (Appendix 4.5). Furthermore, in that zone the B-TO differences for 1972–73 and 1971–72 are only 2.9 and 3.5% respectively. In 1971 to 1973 none of the differences were significant.

   Paddy, Table 4.2. None of the differences significant in any of the years.

   Cotton American, Table 4.5. Not significant in 1972–73.

   Maize desi, Table 4.1. Difference in region 1 significantly positive in 1972/73, significantly negative in 1971/72.

   Groundnuts, Table 4.6. The comparison is between all bullock farms including TH farms and all tractor owning farms.

For a shorter report of the study see A. S. Kahlon, 1976.

farms also hire some tractors. In the context of each of the studies the distinctions will be quite clear.

Tables 2 to 9 are organized as follows. For each study, column (2) lists the items compared. The first line in most studies has a B in column (2) and gives the absolute value of the variables for the bullock farms *in brackets.* The following lines give the percentage difference between bullock farms and other farm types. For example, the line B-TH in column (3) of Table 3 indicates that labor per hectar in the Punjab is 4.3 percent higher on tractor-hiring farms than on bullock farms, with the value of the bullock farm as the basis for the percentage difference. Or the line BP-TOP in the Pudasaini study (Table 5)—on the other hand—is calculated the percentage differences with the value of the BP farm as the basis. *The basis for the percentage change is always the first mentioned farm.*

All Tables are on per hectare basis. Human labor and bullock use is measured either in labor/bullock days or in labor/bullock years, depending on how the authors measured it. Bullock labor is reported in single bullocks, not in pairs. Intensity means gross cropped area over net cropped area in percent. The percentage differences of intensity are *relative to the intensity value of the bullock farms.*[16] Value of production is in Indian Rupees at January 1977 exchange rates. Yields are given in quintals (the quintal is 100 kg) per hectare. Fertilizer use is given either in kg of plant nutrients NPK applied per hectare, or value in Rupees of that applied per hectare. Column (8) is used for various inputs, depending on information available or useful. Labor, bullocks, and production are measured per hectare of farm size. However, farm size is measured sometimes as operated area, cultivated area, or gross cropped area and the basis of measurement is given in the table footnotes, which also list, for each figure given, the table or page number where it was found in the original source. Some general notes on particular features of each study are also presented in the footnotes.

Whenever tests of significance have been reported by the authors they are indicated by * for significance levels of 0.05 and by NS for differences which are not significant at the 5-percent level. Other significance levels were not considered. Where neither * nor NS appear, significant tests were not performed.

[15]For example, if bullock farms have an intensity level of 150% and the tractor farms of 170%, the gain in intensity is 13.3% and not 20%. This corresponds to a 13.3% rise in gross cropped area and thus measures correctly the increase in area cropped. Some studies (for example Narayana) report intensity as gross cropped area over operated area. As long as fallow land is insignificant, this would not lead to distortions.

Cropping Intensity

In areas where few opportunities exist for farm size expansion, the effect of additional power on cropping intensity is often regarded as a major potential benefit, achievable mainly through fast cultivation between seasons. It should be noted, however, that agricultural systems have existed in the past and at present which achieved double-and even triple-cropping without tractor use.[17]

Punjab and Haryana: The Punjab and Haryana studies (for India and Pakistan) summarized in Tables 2, 3, and 4 provide little support for the thesis that tractorization is a major factor contributing to cropping intensity. The gains reported are in the area of zero to 10 percent of the cropping intensity achieved by bullock farms or prior to tractorization. Negative intensity effects are also reported by Kahlon. A statistically significant increase in cropping intensity is reported only for pure tractor farms (B-TO) in strata 2 of the Indian Punjab. Note however, that in that strata tractor farmers who also own bullocks do not show any increase in intensity over bullock farmers, despite the fact that they are probably in the best power position.

The *before* and *after* study in Pakistan similarly shows an intensity increase of only 7 percent. For reasons connected with the phenomenal size growth of these farms (discussed in the footnote below), this is probably an overstatement of the true intensity gain.[18] Since the proportion of sample farms owning tubewells increased from 45 to 60 percent during the same period, the modest increase in intensity cannnot exclusively be linked with the tractorization process.

The largest intensity increase occurred in the smallest farm-size

[17]See, for example, the study of Mandal and Prasad where bullock farms achieve 200% intensities (Table 9). High intentensity levels were achieved in Taiwan long before tractorization. Weng Chieh Lai in 1972 reported that in 1961 the multiple cropping index for Taiwan was 186 when there were only 3708 power tillers in the country (You Tsao Wang). This figure rose to 21,153 at the end of 1968 but the cropping intensity index in 1969 was at almost the same level—184.

[18]Note (Table 4, Panel 7) that over the study period farm sire grew by 142%!. The data collected give the cropping intensity on the land operated before and after the farms grew, but it is not known at what intensity the acquired land was farmed before transfer of land. To judge the impact on intensity of all land now operated by the tractor farmers, the authors must assume a level of intensity for the acquired land. If the farm sizes of the farms from which the land was acquired is smaller than of the acquiring farms, these intensity levels may differ substantially. Before land and tractor acquisition, the farm studied had an intensity of 111.7%. After acquisition, of land and tractor, the intensity was 119.3% Mclnerney and Donaldson show that if the acquired land had been farmed previously at 126%, intensity on the total land area *after* would have remained constant. Since the smallest tractor farms were operating at 122% intensity before and most land was acquired from even smaller bullock farms, the possibility of no change or decline in the intensity is very real.

TABLE 4. Results of tractor surveys (before and after studies) in Punjab (Pakistan and India)

Author Area	Sample size Study year (1)	Comparison (2)	Labor (Year/ha) (3)	Bullocks (no/ha) (4)	Intensity (5)	Yield (q/ha) (6)			Inputs (7)		
									Fertilizer		
						Wheat (HYV)	Rice (Desi)	Maize	Wheat	Rice	Maize
McInerney and Donaldson	202	Before & after	(0.49)	(0.31)	(111.7)	B (17.2)	(18.2)	(10.0)	(Rs. 83.4)	(Rs. 29.3)	(Rs. 7.8)
	1966–67										
Pakistan	1969–70	B-TO	−38.9	−79.0	7.0	B-TO 37.0	−1.1	61.5	17.6	115.2	1027
	I	B-TO			(121.9)					Holding size, all farms (18.2 ha)	
					21.0						
	II	B			(111.0)						
		B-TO			10.4						
	III	B			(127.6)						
		B-TO			−6.0					B-TO 142	
	IV	B			(95.2)						
		B-TO			11.0						
Chopra	130										
Hoshirapur,									Irrigation		
Ludhiana and	Tractor	B		(0.472)	(120.03)				76.3	(15.9 ha)	
Ferozepur	owners	B-TO		−62.2	16.0				20.5	10.6	

TABLE—4

Notes on John P. McInerney and Graham F. Donaldson

Data collected for 1969/70 year. "Before" refers to 1966/67. Most tractors acquired in 1967.

2) In ha; Farm-size classes based on size groups *after* tractorization I : 0.0–24.3; II : 24.3–48.6; III : 48.6–72.8; IV : 72.8 and above. Nos: 50, 83, 35, 24 respectively.
3) Man years per ha operated. Computed from Table 6.1, 6.2 and 6.3. Casual labor is converted into full time man equivalent by using a permanent worker wage rate on the observed expenses for casual labor. The displaced labor includes all labor displaced on the acquired land. Family and permanent labor decreased by 59.3% while casual employment increased by 75.2%. Family labor also includes the labor of the displaced tenants. At least five full time employment opportunities disappeared per tractor.
4) Bullocks owned per ha operated, Table 6.7. Very high tractor utilization: 779 to 1514 hours on average in smallest to largest class.
5) Table 5.7. Land intensity before is only for the area operated before the acquisition of new land. If land was acquired from small farms, there might have been a decrease in intensity since small farms usually have higher cropping intensity. If acquired land had been farmed at more than 126%, the *intensity of cropping would have fallen*.
6) No data on production available.
7) Table 5.9.
8) Table 5.9. in Indian Rs. at 0.92 Pakistan Rupee/Indian Rupee.
9) Table 5.1. Based on cultivated area. Source of land: purchase 13%; increased renting in 28.6%; reduced renting out 32.3%; reclamation and improvement 26.2%; Four and one-half tenants replaced per tractor.

Notes on Kusum Chopra

4) Bullocks owned per ha operated, Table A.
5) Table 8.
8) Net irrigated area as percentage of operated area. Table 3.
9) Table 7, based on operated area.

Table 5. Results of Tractor surveys for Uttar Pradesh, Delhi Territory and Nepal Terai

Author Area	Sample size Study year (1)	Comparison (2)	Labor (days/ha) (3)	Bullocks (4)		Intensity (5)		Value of gross output (Rs/ha) (6)	Yield (q/ha) (7) Sugarcane	Wheat	Paddy	Inputs (8)	Others (9)
Singh & Singh,	102	B	(180)	(0.438)				(4450)	(443)	(18.7)	(16.5)		
Muzaffar Nagar,	1967–68	B-TO	−6.1	−53.4				22.6	25.6	25.1	27.9		
Western Uttar												Fertilizer	
Pradesh													
NCAER,	60	B	(139.5)	(84.2)		(216)		(3486)	(401)	(24.1)		(Rs. 222)	Off farm work
Muzaffar Nagar	1972–73	B-BP	7.6	−21.0		3.7		−3.8	1.3	−3.2		−22.9	in tractor
Western Uttar		B-TOP	−19.0	−75.2		−1.4		13.0	22.2	17.6		0.9	repair
Pradesh		B-TOPTR	−8.8	−72.8		4.1		39.4	41.4	31.6		20.5	3 days/ha
		BP-TOP	−25.0	−68.6		−4.9		17.4	20.6	21.5		31.0	
											Bajra	Fertilizer	
Motilal, Delhi	120	B	(90)			(162.11)		(2000)	(10.92)	(36.11)	(25.39)	(Rs. 167)	
Territory	1968–69	B-TO	−31.8			3.4		47.9	29.7*	15.9*	13.7*	35.1	
										Wheat	Paddy	Improved inputs	Education
Pudasaini,	103	B	(149)	(63.3)		(145.0)		(1539)		19.8	17.2	(Rs. 45)	3.8
Nepal Terai				(a)	(b)	(a)	(b)						
Bara District	1974–75	B-BP	27.8	−14.7		7.1	13.0t	63.0		30.2	21.7	965.6	47.4
		B-TO	18.4	−94.6	−73.7	13.8	36.1t	70.1		22.6	28.3	920.3	84.2
		B-TH	25.5	−15.5	−5.4	15.1	12.2t	43.5		5.7	21.7	506.3	76.3
		B-TOP	22.1	−92.4	−63.0	20.0	51.1t	108.9		26.4	32.6	1267.2	107.9
		BP-TOP	−4.4	−91.6		12.1	n.a.	28.1		−2.9	8.9	28.3	41.1

TABLE—5

Notes on Roshan Singh and B. B. Singh

3) Table 6, days per ha of the cultivated area;
4) Computed from Tables 2 and 4. Bullocks owned per ha of operated area.
6) Gross output per ha Table 7.

Notes on National Council of Applied Economic Research

Sample not farm-size adjusted. All figures on basis of *operated area*. All size groups aggregated on basis of Tables 4 and 14.
3) Table 18.
4) Bullock days per ha Table 29.
5) Table 16.
6) Value of crop output per ha of cropped area, Table 31;
7) Table 33.
8) Total fertilizer expenditure per ha cultivated, Table 35.
9) Table 21.

Notes on G. Motilal

Size adjusted sample. No difference in irrigation. Reduction in fodder area to half. Doubling of the cash crop area. Average of 763 working hours/year, of which only 26 hired out.

3) Days/ha of gross cropped area at 8 hours/day, Table 5.6.
5) Table 5.3.
6) Total output per ha of operated area, Table 5.12.
7) Table 5.4.
8) Manure and fertilizer and pesticides per ha of gross cropped area, Table 5.10.

Notes on Som Pudasaini

Sample not farm-size adjusted. Totals are on the basis of operated or net cropped area.
(3) Table 4, includes only labor in paddy, wheat and sugarcane.
(4) a) Bullock days/ha Cross sectional comparison Table 6.
    b) Reduction in stock of bullocks over time (personal communication of author of March 1977).
(5) Table 3, a = Comparison across farm types,
    b = Comparison over time.
(6) Table 10, Gross revenue per ha of operated area, in Indian Rs.
    1 Nepali Rs. = 0.71 Indian Rs.
(7) Table 2.
(8) Table 1, Expenses on improved inputs, in Indian Rupees, 1 Nepali Rupee = 0.71 Indian Rupee
(9) Table 1, Education of operator in years.

group (group one), and there is a decrease in intensity in farm-size group three.

The only *before* and *after* study in the Indian Punjab is by Chopra, who reports an intensity increase of 16 percent. This intensity increase is associated with a 20.5-percent increase in net irrigated area on these farms, which makes it unlikely that tractors played a major role in enabling the intensification to occur.[19]

We must therefore conclude that tractors have not been a significant factor in intensification on tractor farms in Haryana and the Indian and Pakistan Punjab.

Uttar Pradesh, Delhi Territory, and Nepal Terai (Table 5): In this geographic zone, the evidence regarding intensity increase is more complicated. The Delhi Territory study and the Muzaffarnagar study report virtually no increase in intensity. However, in the Nepal study some intensity effects seem to be present. In this study we have both cross-sectional comparisons between farms and over time comparisons of mechanizing farms.

Large intensity increases are reported over time for farmers acquiring only tractors (36.1%) and farmers acquiring tractors and pumpsets (51.1%). It turns out, however, that cross-sectionally these two categories of farms started out with the lowest initial intensities and thus *caught up.* Since they are the largest farms this may imply that in this area tractors do allow large farms to reach equal or higher intensity levels than small farms.[20] The cross-sectional differences are more modest, and those easily attributable to tractors (B-TO, B-TH, BP-TOP) are around 12 to 15 percent. Note also that pure bullock farms seem to be very much starved of capital. Their fertilizer expenditures per hectare are only about Rs.45, while all other categories spend between 5 to 12 times this amount on fertilizers. Pure bullock farmers are also at a very clear educational disadvantage.

Gujarat (Irrigated Areas, Table 6): The three studies in Gujarat provide no support for the hypothesis that intensity is dependent on tractors. The Desai-Gopinath study and the Sharan *et al.* study both cover Ahmedabad and Kaira district. In these districts, tractor-hiring farms show the highest intensities, with tractor-owning farms having

[19] The increased area is not irrigated by the tractor as the comparison of irrigation expenditures in Table 6 shows.

[20] This is consistent with the conclusion of Ch. Hanumantha Rao (p. 116) from data of the Plan Evaluation Office from Punjab, Andhra Pradesh, Haryana, and Tamil Nadu which indicate that the negative relation between intensity and farm size is steeper for bullock than for tractor farms—i.e. tractors do enable large-size farms to achieve intensity levels usually associated with smaller farms.

equal or marginally lower intensity than bullock farms. Only in Surat district do tractor owners show a statistically significant intensity gain of 13.9 percent, but that is associated with a rise in irrigation from 22 to 60 percent of gross cropped area (i.e., a rise of 181%). In the Tobacco zone, a 15.5-percent increase in cropping intensity is associated with pumpsets, while a gain due to tractors alone is only $5^1/_2$ percent. (Patel and Patel).

Semi-Arid Tracts (Table 7 and 8): The semi-arid areas comprise the seasonally dry tropics where abundant rainfall in short rainy seasons alternates with fairly long dry seasons during which crop growth is dependent on stored soil moisture or irrigation. The red soil areas are represented by Dholka Taluq in Gujarat, while the black soil areas are represented by three areas of Maharashtra, by Dharwar district in Karnataka, and Narsingpur district in Madhya Pradesh, The upland areas III and IV in West Godavari district and Chittoor district in Andhra Pradesh (Table 9) and Coimbatore Taluq (Table 9) are also semi-arid, but the irrigation percentages exceed 50 percent so they are treated separately.

In the semi-arid areas, cropping intensity of bullock farms is slightly in excess of 100 percent and the intensity of tractor farms is not more than 10 percent greater. In the case of Kundgol Taluq in Karnataka (a real kharif-fallow area), tractor farms have a statistically significant lower intensity (by 5.7%) and in Satara district in Maharashtra the tractor farms have a lower intensity of 8.4 percent. Thus, evidence of gains in intensity due to tractors is lacking in semi-arid areas. This lack of gain in intensity in semi-arid areas is not so surprising. After all, cropping is constrained to one season by lack of moisture in these areas, and even a tractor cannot change that.

Bihar: In the area studied by Mandal and Prasad (Table 9) cropping intensity on bullock farms was high—200 percent. There is no evidence that tractors in such high intensity zones lead to further increases in intensity. The bottleneck seems to be the lack of opportunity for summer cropping, due to lack of irrigation facilities for that season.

Andhra Pradesh: Parthasarathy and Abraham studied canal-irrigated low-land areas (Zones I and II) with intensities for bullock farms of 162 and 134 percent. It also covers well-and tank-irrigated upland areas (Zones III and IV) with cropping intensities of 100 percent in bullock-operated farms. In none of these areas do tractor farms have higher intensities than do bullock farms. The Narayana (1977) study

TABLE 6. Results of Tractor surveys for Gujarat (irrigated areas).

Author Area	Sample size Study year (1)	Com-pari-son (2)	Labor (days/ha) (3)	Bullocks (4)	Intensity (5)	Value of gross output (Rs/ha) (6)	Yield (Rs/ha) (7)			Fertilizer (Kg/ha) (8)			Edu-cation (9)	Irrigation (10)
							Paddy	Wheat	Pearl Millet	Paddy	Wheat	Pearl Millet		
Desai and Gopinath Gujarat	92	B	(148)	(10.2)	(146)	(3017)	(2500)	(2869)	(1216)	(179.0)	(83.6)	(37.7)	5.3	(Rs. 2151)
Dascroi, (Ahmedabad dist.)	1972–73	B-TH	8.1 NS	−31.6	14.4	13.7*							7.5	14.1
		B-TO	5.4 NS	−63.5	1.4	15.9*	15.2	16.6	17.6	26.8	−0.2	196.3	20.8	13.5
							To-bacco	P. Millet	Cotton	To bacco	P. Millet	Cotton		
Anand (Kara dist.)	90	B	(173)	(7.05)	(123)	(3731)	(4112)	(1376)	(5303)	(143.6)	(52.3)	(130.3)	6.7	(Rs. 279)
	1972–73	B-TH	11.0	−47.8	21.1	30.6*							22.4	122.9
		B-TO	8.7	−81.6	1.6	38.9*	39.5	−4.4	7.0	199.4	14.7	121.9	31.3	365.9
Sharan, Mathur & Viswanath, Gujarat.	1971–72													
Zone III	55	B		(0.56)	(138)									(68%)
Dascroi		B-TH		−17.4	7.2 NS									2.9
(Ahmedabad dt.)		B-TO		−51.9	−9.4 NS									5.9
Zone II, Anand	51	B		(0.36)	(156)									(77%)
(Kaira dt.)		B-TH		4.0	2.6 NS									14.3
Amreli (Kodinar dt.)		B-TO		−41.7	−1.9 NS									18.2
Zone I, Surat	55	B		(0.48)	(101)									(22%)
(Kamrej)		B-TH		−14.5	8.9*									131.8
		B-TO		−42.8	13.9*									181.8
Patel & Patel,	100	B	112.6		(110)									
Gujarat Tobacco	1972–73	B-BP	32.2		15.5									
Zone.		B-TO	21.9		5.5									
		B-TOP	32.2		20.9									

Table—6

Notes on D. K. Desai and C. Gopinath

The samples are not farm-size adjusted. In all three areas tractor farms are almost twice as large as Bullock- and Tractor-hire-farms. The "before and after" comparison of operated area is as follows for the TO farms: Dascroi + 11.2%; Anand + 18.4%; Dholka + 0.0%; Table 4.3. Anand is a tobacco area in which TO farms have 45.7% of area under tobacco while TH farms and B farms have 33.0 and 31.5% of area under tobacco. Tractor farms already had as much area under tobacco before tractor purchase.

3) Man-days per ha of operated area, Table 4.1. After covariance analysis adjusting for size, irrigation, fertilizer, bullock labor, human labor, tractor power and cropping intensity, the differences in labor use are not significant (Table 5.7).
4) Bullock days per ha. (or, more probably, bullock pair days). Computed from Table 4.24 using size from Table 4.3.
5) Table 4.13.
6) Table 5.4. Most probably on basis of operated area. In Dascroi and Anand the farm type differences remained significant after covariance analysis adjusted for size, irrigation, fertilizer, bullock labor, human labor, tractor power and, croping intensity, Table 5.3.
7) In rupees of gross return per ha Table 7.9. The crops are in order of importance in cropping pattern.
8) In kg per ha, Table 4.26.
9) Education index 9 (years) computed from Table 3.3 by assigning the following year numbers to the school data: Primary 5, Secondary 10, SSC 11, Under-Graduate 13, Graduate 15, Post-Graduate 16. To the extent that all operators with primary and secondary schooling have not completed these schools, the index may overstate average of schooling.
10) Value of irrigation investment per ha of operated area, Table 3.7.

Notes on Girja Sharan, D. P. Mathur, Maya Viswanath

Sample not farm-size adjusted. TO farms more than twice the size of B farms.

4) Computed from Table 2.5. In bullocks owned per ha.
5) Table 2.7.
10) Percent of gross cropped area. Table 2.6.

Notes on N. T. Patel and M. S. Patel

Sample not farm-size adjusted.

3) Days per ha.
5) Intensity.

Table 7. Semi-arid zones in Karnataka, Gujarat, and Madhya Pradesh.

Author Area	Sample size Study year (1)	Comparison (2)	Labor (days/ha) (3)	Bullocks (no/ha) (4)	Intensity (5)	Value of gross output per ha (6) Rs/ha)	Yield (7)			Inputs (8)			(9)	(10)
							Chillies	Groundnuts	Sorghum	Fertilizer	Commercial crops			
Chandramouli, Dharwar Dist., Karnataka, Kundgol Tq. (K)	100	K:B B-TO	(51.4) 2.1	(15.3) −44.3	(102.3) 1.3 NS	(2077) 52.9*	(Rs.4261) 40.1*	(Rs.2840) 13.5*	(Rs.1244) 41.3*	(Rs.243) 60.2	(55.7) 12.6*			
							Cotton	Wheat						
Transition Zone Navalgund (N) Dry Zone	1973-74	N:B B-TO	(26.7) −12.9	(13.1) −42.7	(109.3) −5.7*	(923) 5.0NS	(Rs. 943) 12.8 NS	(Rs. 651) 28.0 NS	(Rs. 489) 5.4 NS	(Rs. 118) −4.9	(35.8) 8.5 NS			
				(a) (b)			Wheat (HYV)	Chickpea	Sorghum					
Misra, Narsinghpur dt., Madhya Pradesh	100 1974-75	B B-TO	(57.5) −52.0	(52.4) (0.58) 82.0 −54.0	(105.9) 8.2		(35.0) +20.0	(8.0) +25.0	(10.1) +16.4					
										Fertilizer				
							Wheat	Cotton	Sorghum	Wheat	Cotton	Sorghum	Education	Irrigation
Desai-Gopinath, Dholka (Ahmedabad dt.)	50 1973-74	B B-TO	(41.0) 0.0NS	(4.5) −63.9	(103) 4.9	(1164) −4.6 NS	(Rs.1198) −7.6	(Rs.1170) 17.4	(Rs.762) −8.3	(15.2) −23.0	(26.0) 12.4	(7.9) −60.6	(5.8) 1.7	(Rs.284) −41.2

(Notes to Desai-Gopinath see Table 5)

TABLE—7

Notes on K. S. Chandra Mouli

The sample is not farm size adjusted.

3) Man-days per ha of operational holding, Table 7.
4) Bullock days per ha of operational holding, Table 7.
5) Table 2 and Table 5.
6) Table 10, 11, Rs. per ha of operated area.
7) Table 10, 11, Rs. of gross return per ha.
8a) Fertilizer and manure expenditure per ha of operated area, Table 7.
8b) Table 2 and 5.

Notes on S.P. Misra

Sample not random, but size adjusted.

Average farm size B : 40.4 ha., TO : 45.9 ha. Crops with high cash outlays grown more on tractor farms.

3) Labor days per ha of gross cropped area, Table 1.5.
4a) Bullock days per ha of gross cropped area, Table 1.5.
4b) Bullocks owned per ha of operated area. Computed from Tables 1.1 and 1.5.
5) Table 1.1.
7) Quintals per ha, Table 1.3.

Notes to D.K. Desai and C. Gopinath see Table 6.

covers a paddy-groundnut zone in Chittoor district. Here, tractor farms have an intensity gain of 9 percent over bullock farms.

Tamil Nadu: Coimbatore taluq is the only study from Tamil Nadu (Table 9). It represents the only case of statistically significant intensity increase which cannot be shown to be due to higher irrigation. Intensity on tractor farms is 20 percent higher than on bullock farms, but tractor farms have only 58 percent of their land with irrigation facilities; bullock farms have 68 percent. Irrigation is from wells and substantial areas are under garden crops such as fruits, vegetables, or spices.

These studies taken together lend little support to the hypothesis that tractors are an important factor in crop intensification. In most cases where substantial differences exist, they correspond to similar or larger differences in irrigation facilities. One exception is the study in Coimbatore taluq which shows a 20-percent increase in intensity without an increase in irrigation. The other exception is the larger tractor farms in Nepal, which seem to have been able to more than offset an initial intensity advantage of smaller bullock or custom-hire farms by purchasing tractors.

Yield Effects

No attempt has been made to review experiment station evidence. A demonstration of yield effects on experiment stations with sophisticated equipment has little value unless it is also accompanied by a benefit-cost analysis which takes account of additional costs. If additional costs do not fall short of additional returns by a substantial margin, there is no chance that farmers would adopt these yield-increasing techniques.[21]

Evidence presented by these surveys indicates that there are many instances in which tractor farms do have higher yields than bullock-operated farms (Table 1). Only three studies, however, present statistical tests of the differences of yields (Kahlon 1975, 1976, Motilal, Chandra Mouli). Of 19 statistically significant yield differences, 2 fall in the range of minus 10 to plus 10 percent, 16 are larger than + 10 percent and 1 falls below - 10 percent. It is thus safe to

[21]G. W. Giles (1975) presents a summary of on-farm trials with improved bullock-drawn equipments carried out in India in 1964-65. Sixty nonreplicated trials of a seed cum fertilizer drill resulted in an average yield gain of 12.5%, a difference not statistically significant. Eighteen nonreplicated trails with a maize planter gave an average yield increase of 40%, but again the difference lacked statistical significance. For experiemental evidence that power tillers do not tend to raise yields in Japanese rice culture, see Tsuchiya, 1972.

assume that we must look, for differences of more than 10 percent to have a reasonable chance that they are statistically significant.[22]

Punjab and Haryana (Tables 2 to 4): R. K. Sharma, Kahlon, and Mclnerney-Donaldson present yield effects. In the Haryana study, tractor farms had a 7-percent advantage in wheat and a 13.3-percent advantage in rice yields. However, they also used 44 percent more fertilizer per cultivated hectare and the modest yield advance cannot be regarded as a tractor effect.

Of all yield effects reported by Kahlon, only the 1973-74 results for the dominant crops in each area are included. It should be noted that in 1971-72 and 1972-73 Kahlon found *not one single* statistically significant yield difference between tractor farms and bullock farms (which at that time included both tractor-hiring and pure bullock farms). The wheat-yield differences are significantly positive in region 2, 3 and 5. However, in region 2, they are confined to farms with both tractor and bullocks, while in region 3 they occur only on the custom and pure tractor farms, but not on the farms owning both tractor and bullocks. Finally, when wheat yields were adjusted by covariance analysis for fertilizer use, the yield difference remains statistically significant only for region 5.

In HYV rice, Kahlon found no statistically significant effects in any region in any year of his inquiry. Of the other major crops in different regions, maize differences in region 1 and the cotton differences in region 5 are statistically significant. Overall, the 3-year study of Kahlon shows practically no support for positive yield effects due to tractor cultivation.[23]

Mclnerney-Donaldson show no yield effect of tractors in desi rice. There is also no effect on cotton and sugarcane (not reported in Table 4). However, it shows a 37-percent yield increase in wheat and a 61.3-percent increase in maize between 1966-67 and 1969-70. The wheat and maize yield differences are associated with a 17 percent and a tenfold increase in fertilizer use respectively during the same period.[24] Furthermore, for most of these farmers 1966 was the first year of use of the HYV wheat varieties; the 1965 seeding to these

[22]The tractor effect is usually not confounded with variety effects or irrigation effects, because most authors do distinguish between desi and HVV varieties and between irrigated and rainfed crops.

[23]One may argue that yield effects become available only by the use of modern seeding equipment, and we know that in most cases tractor farmers do not own such equipment. However, in region 1 as many as 81% of the tractor owners do own a seed cum fertilizer drill used mainly for wheat. But even in this case, wheat yields of tractor-operated farms are not statistically significantly higher in any of the 3 years.

[24]Too much emphasis should not be put on excessively high percentage changes. They usually occur when an input use on bullock farms is practically nil. In such cases,

TABLE 8. Semi-arid zones in Maharashtra

Author Area	Sample size Study year (1)	Comparison (2)	Labor (days/ha) (3)	Bullocks (no/ha) (4)		Intensity (5)	Irrigation (6)	Farm size (7)	
				(a)	(b)				Cultivated area
Sapre, Dhulia dist., Rich black soil plain.	76 1966-67	Before and after	(n.a.)	0.12	0.16	(114)			(39.3 ha)
		B-TO	Zero	−12.7	−38.2	6.0			3.6
Pawar & Acharya, Satara Maharashtra.	100 early 70's	BC	(55)	(27.4)		(130.2)	(27.5)	(3.8)	
		BC-TO	24.8	−65.6		−8.4	+85.1	+156.5	
				Stock	Flow				
Acharya et. al. Maharashtra.	96 1972-73	B	399	(Rs. 875)	(86)	(111)			
		B-TH	+0.4	−25.1	−21.4	−7.2			
		B-TO	−6.3	−30.2	−63.5	−6.3			

TABLE 8

Notes on S. G. Sapre

Sample not strictly random.

3) Permanent servants and family members only (page 51).
4) Study of bullocks per ha page 51 and Table 3.4.
   (a) refers to actual observed bullock pairs while (b) is technological requirements to do the job on the tractorized farms.
5) Based on page 45.
8) Table 2.3 and page 39. Based on cultivated area. Of total increase in area, 2.2% came from land reclamation and improvement. No reduced leasing out reported!

Notes on Jagannatha Rao P. Pawar and T. K. T. Acharya

The paper reports results from Jalgaon, Satara and Ahmednagar districts. Only the Satara results are reported because only this district contains both bullock operated and tractor operated farms. Sample is not farmsize adjusted.

3) Per cropped ha Table III.
4) Bullock days per cropped ha, Table III.
5) Table I.
8) Table I. Irrigation as percent of operated area.

Notes on T. K. T. Acharya, Jagannatha Rao, R. Pawar, Bhaskar Rao

The farm classes are not size adjusted and there are the following numbers in each class:

B : 16; B-TH : 62; B-TO : 18;

3) Table 6.
4) a) Value of drought animals per ha. Table 4.
   b) Bullock days per ha in sugarcane cultivation. Table 6.
5) Labor days per ha in sugarcane cultivation. Table 6.
8) Table 1, as percent of operated area.

TABLE 9. Results of tractor surveys in Bihar, coastal Andhra, and Tamil Nadu.

Author Area	Sample size Study year (1)	Comparison (2)	Labor (days/ha) (3)	Bullocks (no/ha) (4)	Intensity (5)	Value of gross output (Rs/ha) (6)	Yield (7) Paddy	Yield (7) Wheat	Yield (7) Summer paddy	Inputs (8) Fertilizer	Inputs (8) Irrigation	Inputs (8) Land revenue
Mandal and	60	B	(Rs. 342)	(Rs. 69)	(199.6)	(1920)	(47.2)	(27.4)	(76.4)	(Rs. 229)	(Rs. 60.6)	(Rs. 23)
Prasad, Sahabad	1973–74	B-TH	−5.0	−26.4	−3.8	15.2	9.1	5.2	9.5	6.0	7.2	−17.0
dist.		B-TO	11.5	−100.0	1.7	24.1	9 7	3.9	28.6	31.8	9.0	−15.0
Bihar												
Parthasarathi								Paddy	Paddy			
and Abraham							Kharif	Kharif	Rabi			Cultivated
West Godavari dt.							(HYV)	(desi)	(HYV)			area %
Andhra Pradesh	312	I.B	(85.9)	(Rs. 199)	(162)	(2793)	(35.4)	(25 7)	(40.3)	(Rs. 154)	(100)	(100)
	1972–73	B-TH	3 2	na}	−1.9	8.3	−4.5	−2.3	−2 3	64.9	0.0	0.0
		B-TO	7.7	−42 2}					Sugarcane			
		II.B	(226.08)	(Rs. 560)	(134)	(6205)	(47 8)	(35.9)	(104)	(Rs. 558)	(100)	(100)
		B-TH	−16 5	na}	−4.7	−15.4	−12.7	−7.0	−9.3	−3.6	0.0	
		B-TO	−13.7	−71 4}					Tobacco			
		III.B	(259.6)	(Rs. 410)	(100)	(2443)	(36.1)	(9.0)	(18.6)	(Rs. 971)	(66.67)	(77.0)
		B-TH	17.4	na}	0.0	9.9	−34.2	−164.2	−2.9	36.3	33.9	−20.0
		B-TO	−25.2	−45.4}					Tobacco			
		IV.B	(155.1)	(Rs. 162)	(100)	(2747)	(13.9)	(14.1)	(12.1)	(Rs. 239)	(65.36)	(76.1)
		B-TH	4.3	na}	0.0	14.0	63.9	20.4	−8.2	39.3	1.0	−5.6
		B-TO	9.4	−54.3}								
									Rainfed			
							Kharif	Rabi	Ground-		Irri-	
							paddy	paddy	nuts	Fertilizer	gation	
Narayana	115	B	(166.9)	(.56)	(103.8)	(2767)	(Rs. 3087)	(Rs. 3405)	(Rs. 1566)	(Rs. 105.93)	(63.1%)	
Chittoor,	1972–73	B-TH	−10.8	—	−.08	−3.0	−10.7	−11.9	+1.8	+25.8	−7.4	
Andhra Pradesh		B-TO	−15.2	−71.7	+9.0	+20.3	−7.1	+.4	+29.9	+62.0	21.8	
										Fertilization & seeding		
								Ground-			Ground-	
Umakesan	90						Cotton	nut	Sorghum	Cotton	nut	Sorghum
Coimbatore	1969–70	B	(134.7)	(0.23)	(135.4)	(5985)	(7.9)	(8.4)	(9.6)	(Rs. 356)	(Rs. 379)	(Rs. 307)
· Tamil Nadu		B-TO	6 4	−44.4	20.2*	30.6*	−.9	31.4	0 0	−5.4	28.7	23.8

TABLE—9

Notes on G. C. Mandal and R. N. Prasad

Sample not farm-size adjusted.
3), 4) Rupees per acre operation holding for all categories of labor and bullocks, computed using Table 4.1.
5) Tables 2.1.A., 2.1.B., 2.1.C.
6) Value of output per ha of operated area. Net return per acre highest on custom farms. Table 4.2.
7) Tables 2.1.A., 2.1.B., 2.1.C. Note that on tractor farms rabi, masur and mixed crops had lower yields by 20.4 and 14.7% than on bullock farms. Note that summer paddy is only 6% of gross cropped area.
8) Rs. per acre operated, Table 4.1.

Notes on G. Parthasarathy and V. Abraham

Sample not farm-size adjusted.
Zone I Paddy—Canal ....(123 farms)
Zone II Paddy—Sugarcane-Canal ....(73 farms)
Zone III Paddy—Tobacco, upland with tanks & wells ....(87 farms)
Zone IV Paddy—Millet, upland dry ....(39 farms)
Tractor use is positively and significantly associated with HYV use farm-size, and literacy, but not with tenure or age (Table I-4).
3) Man-days per cropped ha Table I-5; A large loss of labor is associated with lack of bullocks maintenance.
4) Rs. per ha of operated area Table I-1.
5) Table I-12.
6) Gross value per operated ha Table I-16. In Zone III & IV tractor users plant more tobacco.
7) Table I-15.
8) Fertilizer + manure + pesticides, Rs. per operated ha Table I-17. Irrigation as percent of cultivated area, Table I-11; Cultivated area as percent of operated area I-10.

Notes to D. L. Narayana

Study states that tractor farmers reclaimed 9% of their cultivated area due to tractor. Extreme size differences between farm classes.
3. Table IV. 18 per ha of cultivated area. Computed by dividing labor hours by 8 to arrive at labor days.
4. Bullocks owned per ha operated after purchase of tractor, table IV. 19.
5. Table IV. 4.
6. Table IV. 21, per ha of gross cropped area.
7. Computed from tables V4 and IV-2, as area weighted averages across clusters.
8. Fertilizer expenditure per ha of cropped area, Table IV. 20. Irrigation: % of gross cropped area irrigated Table IV. 3. Labour use in repairs: Days of labor if work in repair shops per ha of area cultivated by tractor owners IV. 39/.

Notes on R. Umakesan

Wheat and chickpea area. Sample with extreme size differences. Average size: B : 24.7 ha.; TO : 44.2 ha; Irrigation percent in operated area (wetland + "garden land") B : 65, TO : 58 (Table 5). No significant difference in cropping pattern by Spearman rank-correlation coefficient.
3) Table 14 and Table 15 (days per ha. operated).
4) Bullock per ha. of operated area, Table 5.
5) Table 7 and Appendix Table VII. The author used an unusual definition of cropping intensity, namely gross cropped area to operated area, rather than gross cropped area to net cropped area. (Personal communication by the author.)
6) Table 7 and Appendix Table X. Value of total product per ha. of operational holding. It is not clear whether this includes livestock products or not.
7) All dry crops quintal/ha. Yield differences were less than 10% for the other three dry crops.
8) This cost is for fertilizer, manures and seeds plus the cost of applying them. Table 12.

varieties in the whole of Pakistan totaled only about 5000 hectares.[25] We would thus expect a yield increase over the 3 study years from learning effects alone.

Uttar Pradesh, Delhi Territory, and Nepal Terai: In both Uttar Pradesh studies, tractor farms have a yield advantage in sugarcane and wheat ranging from 17.6 to 41 percent. Furthermore, the yield effects are not confounded with irrigation, since the NCAER study shows no yield effect for B-BP comparison and a 20-percent yield effect for the BP-TOP comparison. The Singh and Singh study presents no data on fertilizer use. In the NCAER study, the largest yield differences are associated with 20.5-and 31-percent increases in fertilizer use from an already high level of 222 Rs. per hectare of operated area. These are substantial, but not massive increases in fertilizer use. However, yield effects of 17.6 to 22.2 percent are also associated with no increase in fertilizer in the B-TOP comparison. The situation is therefore far from clear. The problem is further aggravated by the small sample size for the NCAER study as a whole—only 11 farms in the B class and only 6 in the TOP class.

In a study not reported in Table 5, Singh and Chancellor used regression analysis on fieldwise wheal and maize data of 26 farmers from Meerut district. They conclude that "There is little evidence to show that significant increases in crop yields can be effected by the mere substitution of mechanical power for animal power under circumstances in which the timeliness or the quality of work is not changed" (p. 813).

In the Delhi territory and Nepal studies (Table 5), yield differences vary between 10 and 30 percent (significant in the case of Delhi territory). Fertilizer is the most likely cause of the yield differences. In Delhi territory, tractor farms use 35 percent more fertilizer and in the Nepal case all yield differences in excess of 20 percent are associated with more than sixfold increases in expenditures on seeds and pesticides. Note also that in the Delhi territory study, pearl millet has the smallest yield effect. It is also likely that this crop receives the smallest amount of fertilizer. In either Delhi territory or Nepal, there is little support for a positive yield effect of tractors.

In *Bihar,* only summer paddy has a substantial yield difference (28.6%). However, tractor farms use an additional 31.8 percent of fertilizers on all crops taken together.

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it would be better to look at absolute input use differences, which can be computed from the tables. The fertilizer use on maize rose from Rs.7.80 per ha to around Rs.88.00 in the above case.

[25]Dalrymple, Table 9.

In *Andhra Pradesh* many yield effects on irrigated crops are negative, except for desi paddy in the kharif season in Region III and HYV paddy of Region IV. In both these regions tractor farmers use 36.3 percent more fertilizers. Note further that in Region I tractor farmers use 64.9 percent more fertilizer but do not have higher yields in any crop. One must therefore recognize that one cannot always attribute all yield differences to differences in fertilizer use.

Coimbatore shows a yield effect of 23.9 percent for groundnuts, but fertilizer use is also 28.7 percent higher in that crop, it is thus impossible to attribute this difference to the tractor, in particular because there is no yield effect for the other two crops—cotton and sorghum.

For all regions combined, we are at best left with 5 or 6 out of 118 instances where large yield differences remain in the absence of equally large or larger differences in fertilizer use. These studies fail to provide much support for the yield-increasing effect of tractor cultivation.

Timeliness

One of the benefits of tractorization most stressed by its advocates is the gain in timeliness achieved by tractors. Umakesan for example, using the tractor and bullock coefficients of his survey, presents calculations of how many days would be required to complete field preparation and sowing for the average tractor or nontractor farms of his survey. On average, for the 19 crops considered, tractor farms should be able to complete field preparation and sowing in exactly half the time required by bullock farms (Umakesan, his Table 10). It is also clear that farms owning both tractors and bullocks should be best placed with respect to timeliness.

We have noted earlier, however, that there are very few instances of yield advantages not related to fertilizer-use differences, nor do we find the higher cropping intensities implied in the timeliness argument. Unfortunately, only Kahlon's study in the Punjab quantifies the actual timeliness achieved by farmers in the field situation. His evidence (Table 10) shows frequency distributions of sowings in different time periods for the four classes of farms studied. A roughly 2-month sowing period is split into four 2-week periods and each cell in the table gives the percentages of the fields in a given farm class sown in each of the four periods. The right-hand side of the table lists the number of observations. In those cases with more observations, the evidence is obviously more valuable. At the bottom of the table,

TABLE 10. Frequency distributions of sowings of different farm classes in Kahlon's Punjab (India) study.

Farm Type	Period 1	Period 2	Period 3	Period	Farms (no)	Period 1	Period 2	Period 3	Period 4	Farms (no)
		A. WHEAT OVERALL					*D. PADDY OVERALL*			
B	32.3	37.1	16.9	13.7	124	31.11	53.33	15.56		45
TH	36.3	43.4	17.7	2.7	113	43.33	40.00	16.67		30
TO	33.3	52.9	9.8	3.9	51	42.86	46.43	10.71		28
TOB	34.3	37.2	15.9	12.6	207	33.33	50.00	16.67		60
Average Yield	25.49	24.23	24.06	20.32		46.64	45.72	41.35		
		B. WHEAT REGION 3					*E. MAIZE REGION 1*			
B	34.38	21.88	21.88	21.88	32	—	33.33	66.67		12
TH	23.53	47.06	29.41	—	17	5.88	41.18	52.94		17
TO	37.50	62.50	—	—	8	14.29	57.14	28.57		14
TOB	36.59	29.27	17.07	17.07	41	—	7.69	92.31		13
Average Yield	23.89	24.68	21.83	18.56		15.8	14.79	13.47		
		C. WHEAT REGION 5					*F. COTTON AMERICAN REGION 5*			
B	30.56	33.33	11.11	25.00	36	—	10.34	41.38	48.28	29
TH	45.00	30.00	25.00	—	20	—	11.54	50.00	38.46	26
TO	—	—	—	—	—	—	—	—	—	—
TOB	25.64	30.77	23.08	20.51	78	8.62	13.79	43.10	34.48	58
Average Yield	21.91	26.57	28.04	16.83		14.48	14.27	14.11	12.47	

average yields of the fields falling in each sowing time group are presented, providing a measure of the cost of delays. Consider data for overall wheat, a rabi crop. This is thus the typical double-cropping situation in which timeliness is assumed so important. Delaying sowing from period 1 to period 4 implies a yield loss of about 20 percent, but most of this loss is associated with delays from period 3 to 4. For all farmclasses, sowing is delayed to period 4 in less than 15 percent of the cases. There is little evidence in Table 10 to indicate a strong advantage conveyed by tractor ownership. It is true that pure tractor farms and tractor-hiring farms have only 3.9 and 2.7 percent of their fields delayed to period 4. But pure bullock farms are doing no worse than farms owning both tractors and bullocks (13.7 and 12.6 percent of sowings in period 4). Furthermore, all four classes are able to complete roughly a third of the sowings in period 1, in which tractor-owning farms should have the biggest advantage. The slight superiority of pure tractor and of tractor-hiring farms points to the fact that these farmers are probably the best managers. In what follows, we will find more evidence for this.

Panels b and c of Table 10 present wheat data for those regions separately where tractor farms have the biggest yield advantage in wheat (see Table 3). The picture is much the same. Pure bullock and tractor-cum-bullock farms have the highest and roughly equal proportions of their sowings delayed to the fourth period and tractor farms do not have higher proportions of these fields sown in period 1.

Panel d shows the evidence for all paddy fields. The biggest yield losses are associated with delays to period 3, in which pure bullock farms do no worse than tractor-hiring and tractor-cum-bullock farms. In period 1 they do not complete as much as tractor-owning and tractor-hiring farms, but do better than tractor-cum-buliock farms. In maize in region 1, also a case of high yield differences between farm classes, bullock-only farms do better than tractor-cum-bullock farms, but worse than tractor-only farms. Only in American cotton (a kharif crop) do bullock-only farms do somewhat less well than tractor-operated farms.

Why should the evidence not be in favor of substantial gains in timeliness? First of all, in each crop there seems to be a sowing period of at least a month or 6 weeks during which yields do not decline substantially. In some very arid tracts, such as Rajasthan, such a long sowing period may not be available. The Rajasthan case is discussed at length by Jodha 1974, who attributes the very rapid spread of tractors to the fact that on these sandy to sandy loam soils with very scarce rainfall, a safe sowing period is often only 5 to 6 days—which puts a much higher premium on timeliness than is the case in the heavy soils or irrigated tracts.[26] We thus can conclude that timeliness of operation should be most important in dry areas with scanty rainfall and shallow red and sandy soils.

The most important reason for failure of timeliness effects to show up in the empirical evidence may, however, be the simple economics of capacity utilization—a factor simply neglected in the timeliness debate. It is quite clear that the extent of timeliness in operations achievable by a tractor depends on the amount of tractor capacity.

On a 20-hectare farm, one may not be able to achieve a certain desired timeliness and intensity level with a 20-hp tractor as a sole power source, but a 35-hp tractor may be sufficient and a 50-hp tractor could achieve it very easily. But tractor costs will rise with the increase in tractor power. The increased capacity of the 35-hp tractor is only available at a cost, and the "excess" capacity of the 50-hp tractor may be very costly. But this applies equally to bullocks. Surely there exists a number of bullock pairs which will achieve the timeliness and intensity level of the 35-hp tractor. Assume that six bullock pairs will do that, but that four are not enough. On the other hand 10 bullock pairs might be able to achieve the timeliness of the 50-hp tractor, but some of them might sit idle for much of the year. As we have seen above, whether tractors will achieve better timeliness than bullocks is an empirical question of the cost of the required capacity for any given timeliness and intensity level. If that cost is less for tractors than for bullocks, tractors will lead to gains in timeliness, but only if this is the case. The mere fact that the tractor is faster and stronger than a bullock pair does not guarantee timeliness. It is interesting to note that even the most ardent holders of the net contributor view will usually stress the need for high annual utilization rates of tractors. Low operating costs can be achieved only by higher utilization, which can usually be achieved only by stretching a given tractor over more area, thus reducing the capacity per unit area with negative effects on timeliness.

This argument has to be qualified somewhat. A tractor can be operated in peak periods without a break from sunrise to sunset by

[26] In a cluster of six villages of the arid district of Nagaur alone, the number of tractors increased from 10 in 1964-65 to 59 in 1973-74. In one of the more intensively investigated villages, the number of working bullocks declined from 228 in 1964-65 to 102 in 1973-74; the number of tractors increased from 1 to 12. The average value of fodder (saved) actually sold in 1973-74 was Rs.535 per household, the average expenses on tractor hiring was Rs.556 per household during the same year. Furthermore, during 1964-65 to 1973-74, cultivated land as proportion of total geographical area of the village increased from 86 to 94 percent. The cropping pattern shifted away from more drought-resistant and main fodder crops as tractors ensured planting of other crops well within the safe moisture period (Jodha 1974, 1977).

switching operators or even at night with light. Bullocks do require some hours of rest during the day. This fact may be an important reason for a cost advantage of tractor capacity over bullock capacity, and thus for gains in timeliness in extreme environments such as Rajasthan.

The timeliness debate also neglects the factor that there exist many alternative ways of breaking power or labor bottlenecks. First stationary machines—such as threshers or other harvest-processing machines—can substitute for tractors as well as bullocks. A farmer who finds himself in a bullock bottleneck in the wheat-harvesting period may invest in a thresher rather than a tractor to enable him to shift bullocks from threshing to field preparation. The massive investment in wheat threshers in the Punjab and other wheat-growing areas after 1966 supports this view. It may have done more to break the important May-June labor peak than all tractors taken together.[27] Threshing used to be done by bullocks, and the threshers thus released bullock labor from this task. Stationary engines would also have eased the bullock power constraints via a reduction of Persian wheels and bullock-powered sugarcane crushers.

Second, new short-season varieties are usually given as the main reason for the emergence of bottlenecks where they allow double-or-triple cropping for the first time. But short-season varieties can also be used to increase the turnaround time between crops in areas which have traditionally been double-cropped, thus easing, rather than creating a bottleneck. Third, farmers can shift to other crops with shorter growing seasons, although as we shall see below, this may have a cost. Finally, regions as a whole where rapid agricultural development takes place can import labor from stagnating areas by seasonal or permanent migration. This has been a pervasive phenomenon in all Indian areas which experienced the green revolution. In addition to breaking the bottlenecks, the migration process helps in distributing some of the benefits of agricultural development from the richer dynamic regions to the poorer stagnating ones.

Timeliness could, however, be reflected in a way different from yields and time of sowing. All farmers may recognize the losses associated with delays in sowing. If they cannot seed by a given target date, they may—rather than sowing late and incurring a yield depression—switch to an alternate crop which, though less economical in general, has time to achieve its maximum yield even though sown in the later period.

If this adjustment mechanism to sowing delays caused by insufficient power is a general phenomenon, we should observe little yield difference between bullock and tractor farms for any given crop, but tractor farms-would have a cropping pattern favoring higher-valued and longer-duration crops. This we will investigate in the next section.

Total Value of Crop Production

In terms of total value of crop production per hectare, tractor farms have a substantially higher level of output than nontractor farms (Table 1). The advantage seems large, but it can be due to multiple causes. It is possible to split the total effect into four components, as follows.

+ Percent change in intensity
+ Percent change in average yields
+ Cropping pattern effect (%)
+ Residual effect[28]

Total = Percent change in value of crop production per net cropped hectare.[29]

We have already shown that we cannot ascribe the observed intensity changes or yield changes to the tractor, except in a few special instances. We have also seen that timeliness does not seem to express itself in higher yields on tractor farms and have hypothei/ed that it might instead enable shifts in the cropping pattern towards higher-valued crops. However, there exist at least five possible causes for cropping patterns shifts between bullock, and tractor farms—

- differences in irrigation
  (ruled out in many surveys due to sampling design)
- power availability, i.e. timeliness
- capital or credit availability, enabling the planting of more high valued-high input crops
- greater managerial ability, enabling better perception of the optimal cropping pattern by the farmer[30]
- less need to produce fodder
  (clear tractor effect).

[27]For empirical evidence on this point, see R. Krishna. Also see B. Ahmad for the demonstration of the capacity of threshers to break the most important labor and bullock bottlenecks in the context of a programming solution. A similar point is made by Singh and Day.

[28]A formal derivation of the above result is given in Appendix A. The residual effect is composed of interaction effects between intensity, yield, and cropping pattern effect. If tractor farmers also have a marketing advantage, it would also contain some price effects since output is measured in value terms.

[29]Note that value of livestock production is not included here.

[30]The ability to perceive optimal input combinations and optimal cropping patterns and to adjust them quickly when prices and/or technology change has been termed "allocative ability" by Finis Welch. The evidence of the effect of schooling on allocative ability has recently been reviewed by Schultz. For some evidence in the Philippines, see Halim.

We thus must first compute a cropping pattern effect and then see whether it is attributable to timeliness or fodder reduction (caused by the tractor), or whether it is more likely caused by irrigation, capital availability, or managerial ability—which would lead to cropping pattern differences even in the absence of the tractor.

Table 11 presents a crude measure of the size of the cropping pattern effect for those studies where it is likely to be positive.[31] If it is less than 5 percent, the effect is assumed to be indistinguishable from zero, and these cases are not reported in Table 11.

Of the 39 cases in which it is possible and makes sense to compute a cropping pattern effect, these effects exceed 5 percent in only 15 cases, i.e. in more than 60 percent of all cases, the cropping pattern effect does not even exist and the tractor could not have contributed to higher production per hectare via an impact on the cropping pattern. *Cropping pattern effects are clearly not a general phenomenon.* It remains to be seen whether, in the 15 cases where tractor farms do have higher output per hectare on account of cropping pattern differences, these effects can be attributed to the tractor.

In the northern region comprising *Punjab, Haryana, Delhi Territory, Uttar Pradesh* and *Nepal Terai,* cropping pattern effects are present in nine instances. In Kahlon's study, they arise for the B-TO comparison in region I and II and all three comparisons for region IV. It is hard to believe, however, that in region 1 and II the cropping pattern effects are positive because of tractor ownership, since the effect is not present for farms owning both tractor and bullocks.

In region 11 the effect is an exceptionally large 75.6 percent, but this is accounted for by the fact that tractor farms put an additional *third* of their gross cropped area under potatoes, a high value-high cash input crop. It is also not clear why tractor cultivation should be essential for this shift. Potato transport is a substantial problem, but unlike with sugarcane, speed in transport is not very critical.[32]

In region I and II it is difficult to pinpoint the precise cause of the cropping pattern effect. Area under fodder is substantially reduced and wheat or rice area is increased. Reduction in fodder is clearly due to the tractor and is important in the case of northern

[31]The "crude cropping pattern effect" is computed as follows. From the percent increase in total production per net cropped area, the intensity increase of column 5 is first subtracted. Then, a simple average is computed of whatever yield effects are reported in the studies and again subtracted. This is crude, but the best we can do without much additional information. The residual interaction term is neglected. Note that with access to the original data it would be possible to compute cropping pattern effects precisely, and this should clearly be done in future studies. The resultant is reported as the "crude cropping pattern effect."

[32]If farmers specialize in early potatoes, tractors may convey a substantial marketing advantage.

TABLE 11. Crude cropping pattern effects and their causes.

Author Area	Comparison (1)	Crude Cropping Pattern effect (2)	Important cropping pattern changes: differences in % area under crop — HYV use (3a)	Special crop & cash crop (3b)	Fodder (3c)	Other important changes (3d)
Kahlon, Punjab (India)	I B-TO	14.4				Paddy 8.1
	II B-TO	75.6		Potatoes 30.0[b]	−9.0	−7.9
	IV B-TH	12.6			−5.9	Wheat 7.9
	B-TO	24.3			−6.1	4.3
	B-TOB	12.4			−5.4	0.0
Sharma, Haryana	B-TO	7.2		Sugarcane+Cotton+Oil-seeds. 6.8		
Motilal, Delhi	B-TO	24.7	Wheat+Pearl Millet 23.9	Sugarcane+Cotton+Vegetables 4.1	−9.8	
Pudasaini Nepal Terai	B-TO	30.8				
	BP-TOP	13.0				
Desai-Gopinath Dascroi, Anand	B-TO	9.1				Wheat 5.2 Paddy 2.8
Gujarat a	B-TO	23.3		Tobacco 14.2		Pearl −6.8 Millet
Chandramouli Kundgol	B-TO	20.0	Sorghum 19.5	Groundnut+Chillies+Cotton 8.9		

Mandal-Prasad, Bihar	B-TH	11.2	Rice & Wheat 13.1	
	B-TO	8.3	18.6	
Parthasarathy, Abraham, Andhra Pradesh.	B-TO	13.2	Paddy Kharif 20.6 Rabi 36.0	Rice Monocropping area

Table–11

Source for Col. 9:

A. S. Kahlon, 1975	Table 3.17
G. Motilal, 1971	Tables 5.2, 5.5.
D. K. Desai-C. Gopinath, 1975	Tables 4.8, 4.9
K. S. Chandra Mouli, 1975	Table 2
G. C. Mandal-R.N. Prasad, 1975	Pages 18, 19
G. Parthasarathy-V. Abraham, 1974	Table I-14

3a) Increase in percentage of total area grown to wheat and bajra against local jowar, wheat, and others.

3b,c,d) This increase is in percentage of area under the crop, i.e. in strata 2 of the Kahlon study there is an additional 30% of the area under potatoes.

a) The yields for TH farms are not available.

b) No very exact figure is available since potatoes are listed as miscellaneous crops. However, the text says that miscellaneous crops are mainly potato in this case.

c) Production is measured on the basis of gross cropped area. Therefore, intensity is not substracted for crude cropping pattern effect.

farms which grow special fodder crops. This practice is less prevalent in the east and south of the subcontinent where bullocks are mainly fed on crop residues.

In the Delhi case, the cropping pattern effect is due to a combination of increased use of HYV, additional high-value crops, and fodder reduction. Only the last effect can be clearly attributed to the tractor. In particular the shift to HYV does not aggravate power constraints, because HYVs are usually of shorter duration, leaving more time till the next crop.

In the Nepal Terai, the cropping pattern information is missing, but it looks as if a high cropping pattern effect was associated with especially high difference in schooling; management may be an important factor in reallocation of cropping patterns.

Gujarat: In this case, the cropping pattern effects in Dascroi and Anand taluq are again restricted to tractor owners; custom farms do not seem to benefit from it. Also the largest cropping pattern effect is associated with the largest schooling difference.

In *Dascroi taluq* it is difficult to pin point the precise reason for the cropping pattern effect, although wheat and paddy are expanded. In Anand, however, it is clearly due to the expansion of tobacco on an additional 14.2 percent of the gross cropped area. Again, it is difficult to see in which sense tractorization would be essential to permit such a shift. Furthermore, we noted earlier that in Anand tractor farmers have a very clear advantage in terms of irrigation facilities, which leads to a cropping mix with more high-valued crops even in the absence of tractors.

In *Karnataka* a cropping pattern effect arises out of a combination of an HYV effect and an increase in cash crops, groundnuts, chillies, and cotton of 8.9 percent of the cultivated area. Since this area grows only one crop per year, it is not clear how the tractor can be held responsible for the additional area under cash crops.

In *Bihar* and *Andhra Pradesh,* the cropping pattern effect, where it exists, is probably caused by additional use of HYVs rather than local varieties of rice.

An argument can be made that tractors lead to advantages in marketing and that these may explain some of the shifts to crops of which a very high proportion is marketed, such as the potato case in region II of Kahlon study of the Punjab or the tobacco case of Anand taluq in Gujarat. Unfortunately no study presents evidence on the differential advantage of tractors relative to bullocks or trucks. Another possible hidden source of benefits is the reduction of use of common pasture lands for bullocks which instead can support more sheeps, goats, or milk cattle. Such effects are external to the farm and have not yet been studied carefully and deserve better attention in future studies.

Unless the two sources of benefits just mentioned are very large, we must conclude that we found few instances where the tractor is likely to have been *a sine qua non* of a cropping pattern shift. There is one obvious exception, namely the reduction of area under fodder in the northern areas of the subcontinent. Apart from that, cropping pattern differences are more determined by differential access to capital, irrigation, or human capital.

Tractor Utilization

Use patterns of tractors as reflected by data in the tractor surveys are summarized in Table 12. The main conclusions follow:

1. Tractor utilization is very much related to farm size. This comes across both within regions where larger farms have higher utilization than smaller ones (Government of Punjab, R. K. Sharma, Mclnerney and Donaldson, Motilal) as well as across regions where those regions with larger farm sizes have higher utilization rates than those with smaller farm size (compare for example, Pakistan versus India in Table 12).
2. Small tractor farms rent out a higher proportion of their hours than large ones (Government of Punjab, R. K. Sharma, Mclnerney and Donaldson, Motilal).
3. Tractor-rental markets appear weak in the Indian Punjab, Haryana, and Delhi Territory but fairly well developed in all other Indian areas, with Pakistan somewhere in between.[33] This is not just a farm-size effect, since the Gujarati farms—which rent out a substantial amount of hours—are not much smaller than the Punjab farms studied by Kahlon.
4. Tillage is by far the most important operation, both on farms of owners as well as on farms hiring the tractors (Gujarat). In most cases it accounted for more than hall and often up to three-fourths of the total agricultural uses by the owner himself. (Column 2 as % of column 7).
5. Irrigation by tractors is important in the smaller Punjab farms, in Maharashtra, and in Chittoor district of Andhra Pradesh. Tractors are used for threshing in most regions except Chittoor district (and by owners in Gujarat). Sowing was nowhere an important use, and interculture was not mentioned in any of the studies.

[33]Nowhere, however, do they seem to be as developed as in Thailand and Malaysia as reported by Chancellor.

TABLE 12. Utilization of tractors.

Author Area	Range or average size of farm (ha)	Total hours used	Uses by owners as percent of (1)							
			Tillage	Irri-gation	Tresh-ing	Sow-ing	Trans-port	Total agri. uses	Non-agri. uses	Hired out
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Government of Punjab (India)	7-10	682	35.9	19.9	11.6	1.3	3.4	72.7	19.8	7.5
	10-20	792	43.6	18.7	9.2	3.3	5.8	80.6	17.7	1.7
	> 20	1008	49.7	8.3	11.8	3.6	5.1	79.5	18.8	1.8
Kahlon Punjab (India)	I 10.6	655						70.4	26.9	0.0
	II 9.5	707						90.9	9.0	0.1
	III 10.9	279						87.9	12.1	0.0
	IV 8.3	360						89.5	9.4	1.1
	V 15.5	550						63.4	33.5	3.1
Sharma Haryana	−6-10	(278)	68.6	0.0	12.0	1.0	6.2	87.8		12.2
	10-14	(407)	70.1	1.0	11.3	0.7	10.1	93.1		6.9
	14-20	(575)	68.5	6.9	7.9	0.5	9.8	93.4		6.6
	>720	(870)	73.7	3.9	11.5	1.5	8.0	98.6		1.4
McInerney & Donaldson Punjab (Pakistan)	+0-24	1019								23.6
	24-49	1273								24.7
	+49-73	1325								8.9
	> 73	1523								0.4
Motilal Delhi	0-6	375								9.1
	6-10	672								5.2
	> 10	1243								0.7

Desai & Gopinath Gujarat	Dascroi	TO	9.6	655	28.6	0.0	2.7	0.0	18.6	49.8	5.8	44.3
	Anand	TO	7.1	882	15.1	0.0	0.5	0.1	15.7	31.4	9.5	59.1
	Dholka	TO	35.3	861	25.7	0.0	5.9	3.8	20.7	56.1	6.9	37.0
	Dascroi	TH	4.6	(55)	76.0		12.7		11.3	100		n.appl.
	Anand	TH	3.4	(57)	59.7	0.0	40.3	0.0	0.0	100		n. appl.
Sapre, Maharasntra			41.5	544	(51.6)	(23.2)	n.av.	n.av.	(17.1)	n.av.	n.av.	34.0
Narayana Chittoor, Andhra Pradesh			11.0	475	21.9	10.5	2.9	0.0	12.6	47.9	29.3	22.7

NOTES TO TABLE 12

Columns 2 to 9 are percent of total hours used. Blanks mean not available. N.appl means not applicable. Figures in brackets are not strictly comparable. See footnotes to each study.

Government of Punjab (INDIA) "Economics of Tractor. . . ." : Tables 3.10 and 3.11

Kahlon: "Impact of Mechanization. . . ." : Tables 6.4, column (8) is "hours spent on social work."

Sharma: "Economics of Tractor Cultivation . . ." : Total hours do not include non agricultural uses by owners himself. Hence column (8) is not available. Source: Tables 3.4, 3.5 and Appendix table 10.

McInerney and Donaldson "The consequences of Farm Tractors . . ." : Tables 6.5 and 6.6

Motilal "Resource Allocation . . ." : Table 5.7

Desai—Gopinath "Impact of Farm Tractorization . . ." : Tables 4.18, 4.19, 4.20, 4.22. TH gives the use of tractors on farms which hired the tractors. Column (6) may not all be transport but may include some of the operations where data is not available.

Sapre "A study of tractor Cultivation . . ." : Tables 2.14 and 2.16 (with computation). It is not clear whether the total hours include nonagricultural uses by the farmer. Furthermore, the figure in brackets refer to uses both on own farm and when hired out. Column (6) may also include nonagricultural transport.

Narayana "Economics of Tractor cultivation . . ." : Table IV—13

6. Tractors are intensively used for transport, both for agricultural as well as nonagricultural uses. Where evidence on both is available, total transport (column 6 + 8) *exceeds 23 percent of all hours in evert case* and goes up to 42 percent in Chittoor district. Finally, the fairly large extent of tractors for nonagricultural uses (sometimes called social uses) should be noted. Clearly tractor owners must be deriving substantial consumer benefits from their tractors.

The utilization picture clearly supports the view of tractorization as a selective substitution process based on cost consideration. *In the low wage environment, tractors have comparative advantages at operations which require large amounts of power (tillage) and/or high speeds (transport).* They do not seem to have comparative advantage where neither running speed nor power are overwhelmingly important (seeding, interculture, weed control, etc.). These operations continue to be done largely by bullocks and labor and it may indeed be that costs of the traditional methods are lower than tractor costs (or the opportunity cost of using the tractor compared with transport or hiring it out).[34]

Bullock Use

Bullock use has been measured in three ways in these studies—as decrease in bullock hours (flow measure), as decrease in bullocks owned per hectare (stock measure), and as reductions in Rupees of expenditures on bullocks (including capital costs) per hectare. A comparison of flow measures with stock measures is possible in Gujarat and in Madhya Pradesh. Desai and Gopinath measure in hours while Sharan *et al.* use the stock measure. The first area in both of these studies in Dascroi taluq, and the second area includes Anand taluq in both studies, although Sharan *et al.* also include a taluq in another district. For tractor hirers as well as tractor owners, hours decrease substantially more than stocks. Similarly in Misra's study of Madya Pradesh hours decrease by 82 percent while—on the same farms—stocks decrease only by 50 percent. The greater decline of hours than stocks is in line with expectations, since bullocks are often maintained as a power source or for specific jobs where they continue

[34]Engineers often advocate the use of tractors for many more operations that can be mechanized on the grounds that this would improve capacity utilization. The increased capacity utilization, however, is profitable for the farmer only if the marginal cost of tractor use plus the average cost of the additional machines and implements falls substantially short of the cost of performing the operation by a combination of bullock and hand labor. That a selective mechanization strategy is indeed privately optimal is borne out by the programming studies of Singh and Day (1972, 1975). Clay gives descriptive account of an early phase of a sequence of investments. For evidence of a similar selectivity of the operations covered in early mechanization in Japan, Korea, and Taiwan, see Tsuchiya, 1972; Dong Hi Kim; and Weng Chieh Lai.

to have comparative advantage, or as a back-up power source. Hence the intensity of utilization of bullocks decreases in shifting to tractors.

In most of the area, bullock hours decrease by more than 60 percent for farms which acquire a tractor but continue to maintain bullocks. The major exception is Karnataka, where hours are reduced by only 44.3 and 42.7 percent. Note that in this area average tractor utilization is an almost incredible 1718 hours per year, of which 27 percent is rented out (Chandra Mouli, his Tables 14 and 15).

Bullock stock measures generally decrease by more than 40 percent, which should correspond to decreases in hours by more than 60 percent. The exception is the Sapre study in Maharashtra, which reports a decrease of only 12.7 percent. The author does mention that it is difficult to work the deep black soils of the study area with tractors during the kharif season, and attributes the high retention of bullocks to this reason. This agrees well with the Karnataka black soil area, which has the lowest decrease in hours.

Labor

In the virulent debate about labor displacement of tractors, advocates on both sides often confuse potential from real effects. Concern of tractors as labor displacing sometimes stems from the fact that in developed countries agricultural mechanization has indeed enabled massive labor displacement. However, we have just seen that tractorization is selectively concentrated in operations where labor displacement is not the primary effect. As long as wage rates remain low there is little reason to expect tractors to gain comparative advantage in labor-intensive operations. However, an existing stock of tractors represents an enormous labor-saving potential which is likely to be realized primarily when wages start to rise.

We will discuss first labor per hectare, then the labor effects of *not* investing the capital of tractors in an alternative use, and finally labor per unit of output.

Labor per hectare: In the total of 58 bullock-tractor comparisons reported, 19 have been tested statistically. In not one were differences statistically significant, despite the fact that in one case the difference was minus 22.6 percent and in another it was plus 24.4 percent.

Of the 58 comparisons, slightly more than half fall into the range of minus 10 to plus 10 percent and can be regarded as indistinguishable from zero. In 29 percent of the cases there is a reduction of labor requirements of more than 10 percent and in 19 percent of the cases there is an' increase in excess of 10 percent.

A first conclusion, therefore, is that the *use* of a tractor is associated neither with an increase nor a decrease in labor use per ha, although evidence may slightly favor a decreasing effect.

There is also some slight evidence that tractor ownership leads either to a larger decrease or to a lower increase in labor use per hectare than tractor-hiring. Of the 42 tractor-owner comparisons, about one-third fall below minus 10 percent while of the 16 tractor-hirer comparisons only 2 (12 percent) fall below minus 10 percent.

Those cases where labor use increases are large do require some special attention, Kahlon (1975) reports a 24.4-percent increase for the 10 farms of region 2 in Table 3 (which specialize in potatoes).

In the Nepal Terai (Table 5) the largest increase of 27.8 percent in labor hours occurs when bullock farms acquire pumpsets. As these BP farms acquire tractors, labor use decreases by 4.4 percent. This puts the increases in labor use between the pure bullock farms without pumpsets and the TO, TH, and TOP farms in perspective. Basically the same picture emerges from the Patel and Patel study in Gujarat. Ownership of a pumpset is associated with a 32.2-percent increase in labor use. An addition of a tractor leads to no further gain in labor use, and the large labor use increase in this case is an irrigation, and not a tractor, effect. In West Godavari, an increase of 17.4 percent in labor use occurs for the B-TH comparison in region 3, but labor use for the B-TO comparison declines by 25.2 percent.

We therefore conclude that in all cases where there is substantial increase in labor use by tractor farms, it is associated with shifts in cropping pattern or irrigation, which are an outgrowth of the improved overall capital availability rather than of the tractors per hectare.

The largest decrease in labor hours (38.9%) is reported for Pakistan by Mclnerney and Donaldson in *a before* and *after* study. This case deserves particular attention. The World Bank financed loans for the purchase of tractors in the 45- to 55-hp class at substantial subsidies to the farmers. Smaller tractors were not considered, whereas in India the most popular tractor size is in the 30- to 35-hp class. Land ceilings or tenancy laws in Pakistan did not exist or were ineffective and these 202 farms grew on average from 18.2 ha to 44 ha, more than double their initial size. Intensity increased at most by 7 percent and may have fallen in some cases. The additional land was acquired as follows: purchases (13%), increased renting (28.6%), reduction in land rented out (32.3%), reclamation and improvement (26.2%). Per tractor, an average of 4.5 tenants were replaced. All this happened within a 4-year period.

One should be careful not to attribute all these changes to tractors. 1966 to 1970 was a period in which new varieties and changes in prices made farming much more profitable in Pakistan. This in itself might have induced a trend towards owner cultivation and land reclamation. However, it seems doubtful that in the absence of the tractor the trend would have been as strong. The relatively large tractor size also put a premium on additional farm size.

It is noteworthy that not one of the Indian studies reports such a large size increase. However only Chopra (Punjab) and Desai and Gopinath (Gujarat) studied farm growth over time, and neither reports increases in size due to reduced renting out. There exists, however, some evidence that many Punjabi farmers had a strong incentive to reduce the number of their tenants with the enactment of tenancy laws in 1966, and that the tractor might have been a welcome means to achieve it.

The studies are nearly unanimous in terms of the shifts in labor classes occurring with tractorization. Permanent labor is reduced substantially (fewer bullock drivers), while family labor generally increases. Daily labor increases in most cases; even the Pakistan study reported such an increase.

Only Rudra finds that in a comparison of large bullock operated farms in 11 districts of the Punjab the decrease in daily rated labor-exceeds the—modest—decrease in the number of permanent laborers.

The NCAER study reports *off-farm labor creation* due to tractor-service and repair (not production). Three days of labor per ha are created annually in such activities, which is relatively low.[35] Farm labor days per hectare vary from 31 in semi-arid Dholka taluq to around 60 in the Punjab, and a maximum of 1 80 in Muzaffarnagar in Uttar Pradesh. Thus in every case a 10-percent reduction in farm labor is all that is required to offset this off-farm employment creation, and in most instances less than 5 percent reduction in farm labor requirement will do it. Off-farm employment creation by tractors can only accommodate a very small labor displacement by tractors on the farm. Finally, to interpret the changes in labor per hectare, it is useful to also look at a decomposition study of changes in labor input per hectare on average (tractor and nontractor farms) in the Punjab. R. Krishna estimates that between 1968-69 and 1973-74,

[35] The Narayana estimate of 9.3 days per hectare of cultivated area appears far too high, since it implies 105 labor days (8 hours) of repair work per year per tractor. If three persons on average are working on a tractor while it is in the shop, that would imply 35 full days spent per year per tractor in the repair shop. Given that certain repairs like flat tire require only 2 or 3 hours, the number of trips to the repair shop must have been at least as high or even higher. It is hard to believe that farmers would put up with such a high breakdown frequency.

labor use in wheat alone declined from 555.7 to 464.1 hours per hectare, a decline of 16.5 percent. Using a decomposition based on labor coefficients for different operations, he decomposes these changes as follows:

Decomposition of the changes in Total Labor Input per hectare in wheat: Punjab 1968-69 to 1973-74

Effect	Man-hours/ha
1. Irrigation (additional area irrigated)	+ 16.28
2. Variety	+ 17.35
3. Tractor ploughing	- 5.26
4. Irrigation Technology (switch to pumpsets)	- 34.59
5. Mechanical Threshing	- 70.58
	- 14.81

Source: R. Krishna, Table 3, p. 280.

It is obvious that tractor ploughing accounts for a very small fraction of the decline in labor use. Note, however, that only ploughing is considered and all other operations are assumed not to be done by tractor. Under this assumption, threshers have had a far more severe labor-saving effect. This is again because tractor use has been selectively concentrated on high power or high speed operations.[36]

Labor per Unit of Output and Foregone Opportunities for Employment Creation: The fact that tractor farms do not use much less labor per hectare than do bullock farms is often used to disarm tractor opponents who point to the labor-saving nature of tractors. However, this is not a correct view of the labor-displacement problem. First of all, in the Brief Overview Section, we have seen that differences in labor per hectare are correct measures of labor effects only under an extreme net contributor view which attributes all differences in production per hectare to the tractor. Since we have been unable to corroborate this view, and conclude that most of the intensity, yield and cropping pattern effects were not due to tractors, *labor displacement must have been substantially larger.* Under the substitution view, the upper bound for labor displacement would be the measures of labor

[36]To gain further insights into labor displacement by new technology, this decomposition method would be highly useful. Almost any tractor survey, in fact, generates the data required to apply Krishna's decomposition prodecure. In Appendix I, the derivation of a simplified version of Krishna's method is given to illustrate how it works.

per unit of crop production. But since they are only upper bounds and can be easily computed by interested readers, we do not report them in detail.

But this is not all. To judge the labor-displacing effects of tractors, we must ask not only how much labor they displace on farms, but how much employment could have been created by investing the *additional capital* (relative to that which previously was invested in bullocks) elsewhere in the agricultural or in the nonagricultural sector. What have been the foregone opportunities for employment creation? It is clear, for example, that additional investment in canal or well irrigation would have *created* additional employment rather than leave it unaffected or reduced, as the tractor investment did. Investment of the additional amount of capital in relatively labor-intensive industries would also have created employment rather than leaving it unaffected. To the extent that private investors or government had a choice of channelling the additional savings invested in tractors into alternative uses with positive employment effects, we must count this foregone employment as labor displaced by the tractors.

The government could surely have discouraged tractor investment by excise taxes and higher taxes on tractor fuels, or by discouraging official credit agencies from lending for the purchase of tractors. The question then becomes—what would be the farmer's responses to these policies? Several cases need to be distinguished—farmers who borrowed from official credit agencies might have reduced their overall borrowings and the credit agencies would have had more funds to lend for pumpsets or other farm improvements. More official credit could also have become available for areas without much tractor demand. Farmers financing tractors out of their own savings could have reacted in at least four different ways:

—increase other farm investments;
—increase consumption;
—increase investments in savings deposits or other financial instruments;
—increase direct nonfarm investment.

It stands to reason that each of these uses would have created additional labor needs. Additional farm investment in irrigation facilities or fertilizer and seed inputs would have raised farm employment. Increased consumption would have tended to increase off-farm employment, since farmers tend to spend additional income primarily on labor-intensive commodities (see Mellor), although the purchase of automobiles or jeeps as substitutes for tractors is an exception. Increased investment in financial instruments would have made more savings available to the economy as a whole, and direct nonfarm investment by farmers would have tended to concentrate on the labor intensive small-scale sectors. It is thus likely that preventing farmers from investing into tractors would have tended to create more nonfarm employment than was created by the tractor investment in the relatively capital-intensive tractor industry.

Allied Enterprises

Few studies give any data on the difference between farm types in the production of animal products or fruits and vegetables. Kahlon (1975), Desai and Gopinath, and the NCAER (1973) include data on investment in milch animals (Table 13). Kahlon's study of the Punjab

TABLE 13: Milch animal densities and livestock output

A: Milch animal densities per hectare in the Punjab

B	Pure Bullock farms	3.83
TH	Tractor hiring farms	3.90
TO	Pure Tractor owners	3.59
BTO	Tractor farms with bullocks	4.03

Source: Kahlon 1975, Table 3.16

B: Per hectare investment (Rs.) in milch animals in Gujarat

		Dascroi	Anand	Dholka
B	Bullock farm	293	466	Not available
TH	Tractor hiring farm	373	484	158
TO	Tractor owner	283	270	64

Source: Desai and Gopinath, Tables 3.15 and 4.3

C: Milch animal densities and value of livestock in Uttar Pradesh

	Milch animals per hectare	Livestock output per hectare (Rs)	Number of farms
Bullock	.33	333	11
B with pumps	.32	260	19
Tractor + pumps	.29	351	6
Tractor + pump + Thresher	.43	418	24

Source: Computed from NCAER (1973) Tables 4, 14, 37, and 38.

includes the number of milch animals per holding (which gives a correct picture in this size-adjusted sample). Milch-animal densities hardly vary across farm types; the lowest value is found on pure tractor farms. In Gujarat the situation is similar. In Dascroi taluq, tractor owners invest equally with bullock owners in milch animals, but to a lesser extent than do tractor-hiring firms. In the other two areas, investment in milch animals by tractor owners is substantially less than by the other farm types. In the NCAER (1973) study, milch animals and livestock output were reported on a per farm basis which can be misleading since the sample is not size adjusted. The findings have been converted (Panel C, Table 13) to a per ha basis and aggregated over size classes (which contain sample sizes so small they are of little value individually). It can be seen that tractor farms with threshers have higher milch-animal densities and livestock output than bullock farms, bullock farms with pumpsets, and tractor farms with pumpsets but without threshers. Should we therefore, conclude that *threshers* increase milch-animal density and livestock production? Or is it equally likely that the farms which have all mechanical technology items also have sufficient capital for more livestock production? Anyway, the small sample sizes of the NCAER 1973 study pose real difficulties in interpreting its results.

All three studies together provide little support for the hypothesis that tractors result in farmers specializing much more in livestock production.

Power Tillers

The NCAER (1977) has recently conducted a large survey of power tillers in five states of India. Power tiller production in India in 1974-75 was only 2221, against an installed production capatity of 10,000. No imports occurred. The cost of a tiller plus equipment is approximately Rs20,000—which is very high. Tillers are mostly used for puddling in rice cultivation. Except for garden cultivation, they are generally not suitable for dryland cultivation. As with tractors, use is mainly restricted to land preparation and transport, but use for irrigation is more frequent. It appears that power tiller farms show practically no gain in intensity, that power tillers are strongly bullock-saving and that they reduce labor use per ha slightly (Table 14). The lack of intensity effect is consistent with the evidence from Taiwan (see footnote 17). Total crop output per hectar on power tiller farms exceeds that on bullock farms by an astonishing 119 percent, which does not appear to be a cropping pattern effect but mainly a yield effect. It is unfortunate that input data are not given; they are needed to understand the source of this incredibly large difference. Nor does the study indicate whether the proportion of area under HYV differs. A reanalysis of the data and some new surveys to verify the yield impact of power tillers is needed, in particular since the evidence from Japan does not suggest that power tillers are yield raising (Tsuchiya).

The NCAER study concludes that cost *per rupee of output* is about 15 percent lower on power tiller farms than on bullock farms. Given that output per ha is 119 percent higher, this implies that *cost per hectare* on power tiller farms is roughly 100 percent higher than on

TABLE 14: Summary of findings of studies containing Power Tillers

Areas	Sample Size & Study Year	Season & Seed Types	Compar-ison	Labor Days per ha	Bullock Stock per ha	Intensity	Yield q/ha	Value of Crop Prod. per ha	Fertilizer kg/ha
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
NCAER									
Andhra Pradesh,									
Karnataka, Kerala,	559		B	(168.8)	0.88	140.7			
Tamil Nadu, Bihar.	1974-75		B-TO	−15.4	−54.0	+1.6		+119.0	
(Tillers only)									
Ahmed	459	Monsoon	B	(1230)		(170)	(17.8)		(50)
Bangladesh	1975	Trad.	B-TO	−8 NS		+10 NS	−5 NS		+164*
(includes also tractors)		Monsoon	B	(1573)			(25.2)		(183)
		HYV	B-TO	−22*			−7 NS		+16.2 NS
		Post							
		Monsoon	B	(1638)			(19.6)		(37.5)
		Trad.	B-TO	−39*			−33*		+167*
		Post							
		Monsoon	B	(2403)			(29.9)		(167)
		HYV	B-TO	−27*			0 NS		+57.5*

Table 14

Notes to NCAER Study

The sample was collected for different farm size groups but was not size adjusted. All comparisons presented above have therefore been made as follows: The findings for each size group in each farm class were taken as an unbiased estimate for the size-class. They were then weighed by the area under power tiller farms in each size group (computed from Table 8) or by the number of tractor farms in each size gruop. Therefore the comparisons related to a "study area" of equal size operated either by tillers or tractors. Note that 46.9% of land farmed by tillers was in the largest of the six size groups with sizes exceeding 10 hectares, whereas the smallest size group less than 2 ha. contained only 1.6% of the land under tractor farms.

(4) Labor days of 8 hours per ha operated: Table 14 and area weights.

(5) Bullocks owned per ha operated. Table 12 and farm number weights.

(6) Table 10 and area weights.

(8) Total crop output per ha operated. Table 16b, "All Crops" column and area weights.

Notes to Ahmed Study

The sample covers Bogra, Syleth and Noakhali districts and is not size adjusted. However the 60 tractor or power tiller owning farms have an average size of 0.6 ha while the Bullock farms have an area of 0.8 ha. Number of tractors and power tillers are not given, but the small farm size would indicate that it is mostly power tillers or very small tractors. The data relate to rice which, however, is nearly the total farm output.

(2) Monsoon and post monsoon refer to two different crop seasons and traditional and HYV varieties refers to comparison across farms which grow a particular type of variety in the particular season considered. The comparisons are thus free of season and variety effects.

(4) Tables 5, 6, 7, 8.

(6) The intensity comparison is for all bullock farms vs. all tractor farms. Table 5.

(7) Tables 5, 6, 7, 8.

(8) In kg of various fertilizers per ha, Tables 5, 6, 7, 8.

bullock farms. This cost increase is not broken down into additional use of fertilizers, HYVs, pesticides, and tractor costs. The evidence therefore does not yet permit clear conclusions regarding output effects, as in the case of four-wheel tractors. Nevertheless, there appears to be little difference in intensity, bullock displacement, and labor-displacement effects between two-wheel and four-wheel tractors.

The NCAER attributes the slow growth in demand for the power tiller primarily to its high price. In South-East Asia, attempts have been made to construct and popularize power tillers simpler and cheaper than those of Japanese design. Particular progress has been made in Thailand, where simple 7-hp power tillers sell for about half the price of those in India (Chakkaphak).

The study of Ahmad (1977) on Bangladesh contains both tractor farms and power tiller farms in an unknown proportion. But power tillers and small tractors must predominate because the average size of the tractor/power tiller farms is only 0.6 ha and tractor imports to Bangladesh have been extremely limited.The number of tractor/power tiller farms is only 60 relative to a total sample of 459 farms and these farms come from three different agroclimate zones of Bangladesh. The data are thus not ideal but may still give some indication of the effects of power tillers.

All farms use enormous amounts of labor but the tractor/power tiller farms use between 8 and 39 percent less labor than the bullock farm depending on the season and variety considered. The reduction is statistically significant in three of the four cases considered. Intensity on tractor/power tiller farms is 10 percent higher (but not significant). Fertilizer use is much higher—in three of the four cases the increase exceeds 50 percent—and is statistically significant. Despite this, tractor/power tiller farms have roughly identical or lower yield per ha. Added fertilizer does not seem to be able to fully compensate for lower labor inputs.

The two studies show results for power tillers which are largely consistent with those of the tractor survey. Intensity—if at all—increases only marginally. Power tillers are clearly labor-saving, even on a per ha basis, and do not tend to increase yields.

The evidence reported here puts in doubt the value of agricultural engineering programs such as that of the International Rice Research Institute, which put heavy emphasis on the design and production of low cost power tillers. Wnere wages are as low as in Bangladesh or India even very low cost machines cannot make a substantial growth contribution.

IV. / THE BENEFIT-COST STUDIES

THE tractor surveys provide evidence that the net contributor view of tractorization, except under exceptional circumstances, is incorrect. We therefore have to expect that, on purely agricultural grounds, it would be difficult to show a substantial cost advantage of tractors. The benefit-cost studies address this question and it is well known that some of them report very substantial benefit-cost ratios. A critical examination of some of the major studies is thus in order.

We will see that a bewildering variety of methods have been used in the benefit-cost studies. However, the main methodological divisions relate closely to the Substitution versus Net Contribution debate. Following Sapre (1969), two basic approaches to benefit-cost analysis can be distinguished, with some authors making use of both for comparison purposes. The first is the *Substitution Method* which assumes that everything a tractor can do can be done by bullocks and hand labor. Basically it starts out from the point of view *of the tractor farm* and computes the additional cost of bullocks and hand labor required to produce *the output of the tractor farm* with bullocks and hand labor and subtracts the savings in tractor costs. The estimate of bullock and labor cost is then regarded as the gross benefit of tractorization. This is a very appealing method because it is usually not so difficult to estimate tractor and bullock costs, but is obviously correct only if the substitution view is correct.

The *Budgeting Method,* on the other hand, corresponds to the Net Contributor school. It attempts to quantify the additional output made possible by tractors. In its extreme form it assumes that all observed differences between bullock and tractor farms are attributable to the tractor. Since this is unreasonable, it usually becomes necessary to split the observed output differences into those attributable to the tractor and those which are not, and this is where the main difficulty of the budgeting method lies. Furthermore, once the observed output differences are split up into those attributable to tractors and those not attributable, it becomes necessary to split up the observed differences in labor and bullock use into components associated with those output changes which are attributable to the tractor and those which are caused by other factors. The budgeting method is thus far more demanding than the substitution method.

The benefit-cost analyses make a serious attempt to attribute the output changes correctly. They obviously did not have the comparative evidence summarized in section III available.[37] Sapre and Hanumantha Roa have used both the substitution and the budgeting methods. When attribution of benefits is difficult, this obviously allows the authors to place lower and upper bounds on benefits and costs.

The assumption and the findings of some of the efforts at benefit-cost analysis reviewed here are summarized in Table 15.[38]

On its left hand side, Table 15 first lists all the possible benefits and costs of tractors. The last item under "Bullock Savings" indicate whether the authors assumed partial or full replacement of bullocks by tractors. In the depreciation and interest rows, the assumed lifetime of the assets and the borrowing rates for capital are given where available or applicable (when internal rates of return are computed, borrowing rates do not have to be assumed).

In addition to substitution and budgeting method, studies can be distinguished according to the method used for estimating additional net output under the budgeting method (see last row under additional net output). Survey results are always used to provide the basic input-output data. However, Desai and Gopinath, and Ahmad use linear programming techniques to estimate potential tractor benefits, while Gotch and Yousuf use integer programming techniques.

A third basic difference is the definition of the investment packade considered (Row 7, Capital). Most authors include only the tractor and implements. However, additional net output (which is counted as a benefit in the budgeting method) is often produced with the help of additional fixed and circulating capital such as pumpsets or fertilizers. If these capital items are costed at the borrowing rate of

[37]Some remarks in this section may appear critical of some authors, but they should not be taken as such. It is only now, with the evidence accumulated by them and others, that it becomes possible to disentangle some of the difficult issues and *ex post* certain things appear obvious which were of necessity obscure *ex ante*.

[38]A complete survey of benefit-cost studies has not been attempted.

capital only, this amounts to assuming that their rate of return is equal to the borrowing rate and any excess benefits of these capital items over and above the borrowing rate is attributed to the tractor. It is more appropriate to include additional pumpset investment into the investment package, as McInerney and Donaldson do. This latter procedure will lead to an over-estimation of the rates of return to tractors only if the true rate of return to pumpsets exceeds that to tractors. Finally, some authors do social benefit-cost calculations while others do not. On the surface, it appears futile to compute only private benefit-cost ratios. Surely if farmers invest in tractors, they must be privately profitable. However, there is still an interest in purely private benefit-cost calculations because we are interested in whether farmers invest purely on account of agricultural benefits or whether secondary considerations—such as ease of operations, status, consumer benefits, etc.—also play a role. All studies of cost have confined themselves to agricultural benefits, since other benefits are simply not quantifiable.

Social returns can be calculated on various assumptions, summarized under row 9 in Table 15. Labor saving can be assigned a lower social value if there is little scope for employing the released labor elsewhere. This tends to depress social benefits from the tractors. Foreign exchange can be valued more highly than the controlled rates, which may lead to contradictory effects. It tends to raise fuel and tractor costs (unless fuels are heavily taxed and the taxes are not counted as a social cost), and thus reduces social benefits. However, if a country discriminates against agriculture by reducing output prices below world market levels (as Pakistan did at the time of the Bashir Ahmad study), valuing output at international prices and at the opportunity cost of foreign exchange tends to raise the benefits from tractors if the net additional output counted is large. Other methodological differences will be discussed study by study. Finally, note that all calculations have been done at pre-1973 fuel rates, and that at present fuel prices all net returns would be lower.

Hanumantha Rao computes a large set of internal rates of return. Here only those for the 20-hectare farm are shown; for smaller farm sizes, all rates are much lower. Private returns appear fairly attractive for the 20-hectare farm on labor and bullock cost saving alone (substitution method). Note that Hanumantha Rao assumed full displacement of bullocks. However, bullock displacement has not been complete except in a few farms, and the rates of return realized by farms may thus have been lower.

Under the budgeting method Hanumantha Rao attributed to the tractor all differences in yields, intensity, and cropping pattern found

TABLE 15. Assumption and results of Selected Benefit-Cost Studies

		Hanumantha Rao Punjab, 1969-70		Sapre Maharashtra, 1966-67		McInerney & Donaldson, Pakistan, 1969-70	Gujarat (Anand),[8] 1972-73		Bashir Ahmad[12] Pakistan, 1969-70	Gotch & Yousuf, Pakistan, 1969-70
		Substitution	Budgeting	Substitution	Budgeting	Budgeting	Budgeting	Budgeting	Budgeting	Budgeting
BENEFITS										
Additional[15] net output	Yield gains	—	X	—	—	—	X	X[9]	—	—
	Intensity	—	X	—	X	X	X	X	X	X
	Added Irrigation	—	—	—	X[14]	X	X	X	X	X
	Other Cropping Pattern	—	X	—	—	—	X	X	X	X
	Land Reclamation	—	—	—	X	X	—	—	—	—
	Method of Estimation		Survey[1]	Survey	Survey	Survey	Programming	Programming	Programming	Integer Programming
Labor Saving		X	X	X	X	X	X	X	X	X
Bullock Saving	Depreciation	X	X	X	X	6 yrs	5 yrs	5 yrs	12 yrs	12 yrs
	Interest	X	X	X	X	X[6]	10%	10%	X	10%
	Fodder	X	X	X	X	X	X	—	X	X
	Reducing Hiring	—	—	—	—	—	X	N	N	N
	Loss of Manure	X	X	X	X	—	X	—	—	—
	Full displacement of bullocks	Yes	Yes	No	No	No	No	Yes	Yes	No
Tractor Rentals		—	—	X	X	X	X	X	—	—
COSTS										
Fixed Costs	Depreciation	10 yrs	10 yrs	14.7 yrs	14.7 yrs[3]	X	10 yrs	10 yrs	8 yrs	8 yrs
	Interest	N	N	6.5%	6.5%	N	10%	10%	X	10%
	Tax, Insurance	—	—	X	X	—	?	?	—	—

Variable Costs	Fuels & Repairs	X	X	X	X	X	X	X	X	X
	Driver	X	X	X	X[4]	X	X	?	?	?
Capital	Tractor & Implements	X	X	N	N	X	X	X	X	X
	Pumpsets	—	—	N	N	X	—	—	—	—
	Farm Size (Ha)	20	20	40	40	44	7	7	20	20/10
NET RETURN		Internal rate of return[2]		Annual net benefits		Internal rate of return	Benefit cost ratios		Internal rate of return	
Private		12.5-19.7	29.5-35.7	Rs. 1545	Rs. 1122[5]	57%	1.84[10]	4.40[11]	46%	>10/<15
Social		9.7-19.5	28.5-36.2	—	—	24.1%	—	—	32%	<10/<10
Adjustments for Social Return	Labor	25%, 50%, 75% of wage rate				Zero[7]			Market Wage	Market Wage
	Foreign Exchange		+33%			+100%			+134%	
	Commodity Prices									
	Fuels	X	X			X			X	

Symbols Used: —Not included in benefits or costs
X Included in benefits or costs
N Not applicable

Notes to Table 15

1. Farm management studies, using both over time and cross section comparisons. Additional net return of cultivation 40-45% on large farms and 70% on small farms. Fuel and labor have opposite effects on profitability when adjusted to opportunity costs.
2. Rates of return only shown for 20 ha farm. For 4.5 ha farm rates of return substantially lower. When fuel price rises are taken into account, social benefit/cost ratios drop to below one in all cases except for large farms when all production gains are attributed to the tractor.
3. This is computed by dividing the assumed life of 8000 hours into the average yearly utilization of 545 hours. Bullock depreciation based on observed market prices.
4. Only counted when drivers were actually employed, which was on 20% of farms. Opp. cost of family drivers not counted.
5. Net benefits per year per tractor. Note that depreciation and interest are very low. If we assume only 10 years of life and 10% interest, we would have to deduct approximately an additional Rs. 1500 from these net benefits (assuming a total investment in tractor and equipment of about Rs. 22,000 at current prices). This

would bring the benefits to zero even in the substitution method. Current mid-1970 fuel prices would reduce private benefits even further.

6. Assumes that bullocks were disposed over a 3-year span and adds the proceeds to the net benefit stream in those years.
7. For calculating the economic return and the social return the labor replaced is valued at zero, and output on additional farm size is not counted. This depresses these rates of return. Foreign exchange rate is adjusted only in the social rate of return.
8. Only results for Anand Taluka are shown. Tractor investment in other talukas appears to be unprofitable under most cases considered by Desai and Gopinath. Only results which include custom hiring are shown since without custom hiring profitability is very low.
9. The average yield advantage in the final programming solution is around 16% while the intensity gain is around 35% (as proportion of intensity bullock farm). Computed on basis of cropping pattern is in formation in Table 8.12 and Appendix.
0. This is computed by essentially dividing net benefits on the tractor farms (except for depreciation and interest on tractor equipment) by the total tractor and equipment investments. It amounts to assuming rates of returns to all other investments on the farm are equal to 10%, the borrowing rate on capital, and that entrepreneurial rents are zero.
11. This is computed by dividing all additional benefits of the programmed solution of the tractor farms versus bullock farms by the difference between tractor farms and bullock investment on bullock farms. Some assumptions then mentioned in footnote 11.
12. Only situations with tubewells are discussed. Without tubewells tractors investment is not profitable in any case.
13. We only know that for the 20 acre farm the internal rate of return should be greater than 10% because at 20 ha farm size the tractor enters the optimal solution of all farms which are greater than 10 ha (Table 5.2). At 10 ha we know that internal rate of return must be lower than 15% because the tractor no longer enters the optimal solution at that rate of interest (Table 5.5). When tractors are priced at world market prices, they disappear from all farm sizes in the optimal solutions. Hence internal rate of return must be less than 10% interest rate assumed (Table 5.4). However it appears that output prices may not have been correspondingly adjusted to world market prices.
14. Includes only that part of additional irrigation carried out by tractor and the corresponding intensity gains.
15. All studies considered only *net* output, i.e., the additional fertilizer, labor, etc. costs were subtracted in every case.

between bullock and tractor farms in the Farm Management Studies. The survey evidence now available indicates that this is excessive. The rates of return should thus be closer to those of the substitution method. Social returns of tractors with the more realistic substitution benefits are still fairly attractive (between 9.75 and 19.50 percent), depending on the wage rate assumptions. However, when recalculated at post-1973 fuel prices, all internal rates of return calculated with the substitution method are much lower than 12 percent, and even with the favorable bullock replacement rates assumed tractor investment would be socially unprofitable.[39]

Sapre's study, a pioneering effort, unfortunately is not available in printed form. It extensively discusses the methodological issues and is an unusually careful effort at attributing the additional net output properly. For example, he counts as irrigation benefits ony those areas actually irrigated by tractor and similarly for land reclaimed. His task was easier because tractors were introduced into a technologically stagnant environment in Maharashtra. He confines his efforts to quantifying private net annual benefits, which are Rs. 1,545 per tractor for the substitution method and minus Rs.1,122 per tractor for the budgeting method (in 1966-67 prices). The substitution analysis shows higher benefits because the output of the tractor farms could be produced with fewer additional bullocks than were actually displaced by the tractors.

However, even the modest net benefits are no longer realistic. Farmers can no longer borrow at 6.5-percent interest rates and the limetime of almost 15 years estimated for tractors is surely excessive. At interest rates of 10 percent and a 10-year lifespan of tractors, net benefits should be reduced by about RS. 1,500 per year, thus going to zero—even at the favorable fuel prices of the mid-sixties.

Mclnerney and Donaldson find extremely high private rates of return for the 202 tractor farmers studied in Pakistan. The returns are to a package of tractors and tubewells investments which took place over a period from 1966-70. The authors exclude yield effects and cropping pattern effects from the benefits of the tractors, i.e. the cropping pattern and rate of adoption of HYV is assumed to be the one of 1969. Further, all outputs and current inputs are valued at 1969 prices, thus the very substantial price rises of outputs are not reflected in the rate of return.

The very substantial rates of return derive from the output which

[39]Hanumantha Rao gives only benefit-cost ratios, rather than internal rates of return for post-1972 fuel prices. All benefit-cost ratios for the substitution method are less than 0.55, thus internal rates of return must be less than the 12 percent borrowing rate assumed.

these 202 farmers produced on the additional land acquired and from irrigation with tubewells. Recall that these farms more than doubled in size. We noted earlier that it is probably unlikely that all of the land increase is attributable to the tractor, as at least some of it may be due to the general increase in profitability of farming during the period.

But even if only a fraction of the additional area increase is attributed to the tractor, the benefits remain very large. How large the benefits remain can be seen from the so-called economic return, which is 30 percent (not shown in Table 15). In this calculation the "post-tractor" area of the 202 farms is regarded as a project area, and the net benefits from previously farmed land acquired is not counted as a benefit. Only the net benefit from reclaimed land is attributed to the tractor-cum-tubewell package (a substantial 26.2 percent of all land additions). The "economic" rate of return to the package remains a very attractive 30 percent, even though the labor saving has not been counted as a benefit at all. Since labor is unlikely to have a zero opportunity cost, the economic rate of return is probably an underestimate, as is probably the case with the social rate of 24.1 percent, where the same zero labor valuation has been used. The only difference between the economic and the social return is that international prices have been used to value tractor investment, fuels, and agricultural outputs.

The substantial social rate of return to the tractor-tube-well package is clearly caused by the opportunity for land reclamation and opportunity for tubewell irrigation.

Desai and Gopinath estimate additional net output, both by survey and programming techniques. Of the three taluqs studied by them only the results of Anand are reported. The authors report that in the other taluqs the returns are much lower, even under the extremely favorable assumptions which they made. Furthermore, only results including receipts from tractor rentals are shown. Without renting, all benefits-cost ratios computed by the authors are drastically reduced, most often below 1.0. This shows that renting out of tractors is one way of securing more attractive rates of return.

The benefit-cost ratio of 1.84, based on the survey, is a substantial overestimate. It is derived by dividing the present value of all benefits of the tractor farms by the total tractor and equipment investment. It thus assumes that the rate of return to all other investments—such as irrigation and working capital—is equal to 10 percent, the borrowing rate on capital. It further assumes that land rents are equal to market rental rates and that enterpreneurial rents are zero. Definitely irrigation and working capital investment should also have been counted in the denominator. Tractors and implements are approximately 66 percent of all the capital which should have been counted in the denominator.[40] Under this adjustment, the benefit ratio of 1.84 comes down to about 1.2. Since many of the working capital investments have high benefit-cost ratios, the one for the tractor investment must be even lower.

In the second Desai and Gopinath result and in the remaining two studies, the additional net output of tractors is calculated by comparing programming solutions of tractor farms with those of bullock farms.

The internal rates of return derived in this manner by Desai and Gopinath and by Ahmad reflect special features of their models, rather than high real payoffs to tractors. Desai and Gopinath use the input-output coefficients derived from the surveyed bullock farms for their model of the bullock farm and those of the surveyed tractor farms for the tractor farm model. This implicitly amounts to assuming that tractor farmers, if forced to return to bullock and labor, would reduce their fertilizer and other input levels to those of the bullock farmers which is quite unrealistic for most crops (such as paddy or tobacco) grown on these farms. Furthermore, the programmed tractor farms have 91 percent of their land irrigated while the bullock farms must do with 77 percent. Tractor farms are allowed to spend Rs.27l per hectare on nitrogen, while bullock farms can spend only Rs.214 and working capital is constrained to Rs.3,000 per hectare for tractor farms while bullock farms must make do with Rs.2,500.

It is not surprising that in the final solutions, tractor farms have 35 percent higher intensity and an average yield advantage of 16 percent (computed from their Table 8.12). Nitrogen, and not power, is the most severe constraint facing the programmed farms and it is thus impossible to regard the high benefit-cost ratios of 4.4 as attributable to tractors.[41]

The Two Pakistani studies by Ahmad and Gotsch and Yousuf are stages in a whole series of programming studies done under the guidance of Carl Gotch over a number of years. Ahmad's linear program allows bullock farms equal access to HYV and fertilizer technology, thus both types of farms can use the same production

[40]Total investment would include tractor, implements, irrigation investment, fertilizer and manure, pesticides, and current expenditures on irrigation, tractor, and bullock power. The approximate calculation is based on Desai and Gopinath Tables 3.7, 7.1, and 9.2.

[41]The adjustment of the benefit-cost ratio to total capital invested would already bring this ratio down to around 2.5, even if all the other biases in favor of the tractor farms were accepted.

processes. The internal rates of returns shown are those for situations in which prior investment in tubewells has been made on both the tractor and the bullock farm. *Without tubewells, a switch to tractors is unprofitable in the programmed situation.* The assumption leading to high internal rates of return to tractors is the peculiar bullock constraint. When the farm initially acquires a tubewell, it is not allowed to purchase additional bullocks to alleviate the clear labor bottleneck which arises from added irrigation. However, it is allowed to purchase a tractor. It might be equally or more profitable to add another bullock pair to alleviate the power bottleneck, rather than to shift to tractors. The tractor investment seems to have high returns and lead to large intensity gains over and above the bullock farm, but the bullock farm is unable to exploit its tubewell fully on account of an artificial power constraint.

That this artificial constraint on bullock investment is indeed the source of the high rates of return is clear from the Gotch and Yousuf study, which uses integer programming but is otherwise the identical model of Ahmad's study. With integer programming, it is not possible to compute separate rates of return to different investments. However, it is clear that the procedure only results in tractor (or any other investment) if the internal rate of return exceeds the borrowing rate of 10 percent for fixed capital. From the integer solution it becomes clear that the private internal rate of return must exceed 10 percent for the 20-hectare tractor farm but must be lower than 15 percent for the 10-hectare bullock farm. The results as published do not allow us to put an upper bound on the private rate of return in the 20-hectare farm. However, it is clear that social returns to tractor investment on the 20-hectare farm are less than 10 percent, which is much less than the 32 percent found by Ahmad. The reason is that the integer program chooses additional bullock pairs rather than tractors to overcome the power bottleneck created by the increased tubewell irrigation.

Linear programming efforts thus appear to suffer from a tendency to grossly exaggerate the benefits and intensity gains attributable to tractors. B. M. Sharma's 1975 study of Delhi territory, which is not reported here in detail, also finds large intensity increases in programmed solutions, while his survey results indicate no such gains (his Tables V-l to V-17). Similar problems arise in the programming studies of Punjabi farms by A. C. Sharma. Most often this arises because, unknowingly, farmer behavior is constrained by innocent looking constraints. Even fixing the farm size in a linear program makes it impossible for the linear program to hire additional land which a farmer definitely can.

There is one large programming effort which is not reviewed in detail here because it is not aimed at calculating benefit-cost ratios, but aims at relating investment behavior of Punjabi farmers over time (Singh and Day 1972, 1975). It departs from the usual linear programs in two ways. First it is dynamic, i.e. a sequence of linear programs are followed over time, and second, it splits up mechanical operations into each of its components. The usual programming techniques specify crop-production processes for the tractor farm and the bullock farm and require that all agricultural operation for a given crop-production process be performed either by bullocks or by tractors. Day and Singh, in a much more realistic effort, specify processes for mechanical operations such as land preparation, seeding, interculture, harvesting, threshing, pumping, etc. Several alternative processes are specified for each, so that threshing, for example, can be done by bullocks, tractors, or threshers. In this way the optimal program can choose an investment pattern such that each operation is performed by that technique which has the lowest cost at a given moment. These solutions capture in an impressive way the selective and sequential process of agricultural mechanization in the Punjab and show the clear rationality of the types of mechanization and utilization patterns reported here in Table 12.

The overall conclusion from the benefit-cost analysis is that even without counting the higher post 1973 fuel prices, most rates of returns and benefit cost ratios presented in Table 15 are overestimates of the true rate of returns to tractors. The Mclnerney and Donaldson and the Gotch and Yousuf studies are notable exceptions. Most net benefits, both private and social, should probably be close to the break-even point, either on the positive or negative side and most might be negative at the higher fuel prices of the late seventies. High net benefits seem simply not to be achievable without area expansion, and opportunities for such expansion or for massive land reclamation appear limited in the subcontinent. High private returns are achievable by land acquisition from other farmers (as in the case of the Mclnerney and Donaldson study), but in the absence of true land reclamation the social returns would be very low. Furthermore, the benefit-cost studies are also unanimous in that profitability of tractors on small farms is very low (Hanumantha Rao, Gotsch; compare also with Mclnerney and Donaldson). Small farms could increase benefits by hiring out the tractors, but the survey evidence of farms using hired tractors does not point to a great increase in net output from tractor hiring on those farms.

V. / CONCLUSIONS

THE massive amount of empirical agricultural economies research which has gone into the tractor issue in South Asia enables a much clearer perception of the policy options available to these countries.[42] The tractor surveys fail to provide evidence that tractors are responsible for substantial increases in intensity, yields, timeliness, and gross returns on farms in India, Pakistan, and Nepal.[43] At best, such benefits may exist but are so small that they cannot be detected and statistically supported, even with very massive survey research efforts. This is in marked contrast to new varieties or irrigation, where anybody would be surprised if he failed to find statistically significant yield effects, even in fairly modest survey efforts. Indeed, the fairly consistent picture emerging from the surveys largely supports the view that tractors are substitutes for labor and bullock power, and thus implies that, at existing and constant wages and bullock costs, tractors fail to be a strong engine of growth. They would gain such a role only under rapidly rising prices of those factors of production which they have the potential to replace.

In view of this Finding, many of the benefit-cost studies reported may have overestimated the benefits, both social and private which arise out of the agricultural uses of tractors (see below on the

[42]Other investment or technology choice options are amenable to study by similar research techniques and provide high-payoff research opportunities for the existing or emerging social science research capacity in these countries.

[43]Proponenets of the net contributor view often argue that the evidence on tractors is inconclusive, because it is not the power unit per se which increases yields but the implement going with it and that emphasis should be on implements rather than on the power unit. Unfortunately, little evidence exists on the yield effects of implements at the farm level. Furthermore, since most implements can be designed both for tractors and bullocks, it is not clear how this point should affect policy decisions on tractors. It also needs to be stressed again, as in the section on tractor utilization, that it may be privately optimal for farmers to mechanize initially only those operations where tractors have a comparative advantage even at low wage levels, namely those which require concentrated power and/or high speed.

nonagricultufal uses). Except in situations where area effects are possible—or by renting or buying land from others—*private* returns to tractors from *agricultural operations* must be close to zero, or even negative at current fuel prices.[44]

In the Indian subcontinent there are probably a few areas remaining where tractors are a pre-condition for area expansion by reclamation. In very-arid tracts, such as Rajasthan, tractors may—for a given cost—allow the cultivation of more land than can be done with bullocks, thus also leading to an area effect. In the very arid areas, speed of agricultural transport is also at a premium when compared to more densely populated areas, thus further contribution to a comparative advantage of tractors there. These special cases will continue to provide attractive returns for tractor investment, but apply only to very limited agroeconomic zones.

The basic conclusion that, in the absence of area effects, not only social but also private returns have been lower than found by most benefit-cost studies in the past, and that they are even lower now, leaves a puzzle: *Why have farmers in areas like the Punjab invested massively in tractors and why do they continue to do so?*

In cases such as the Pakistan Punjab, the answer is very clear. The tractor made farm growth and self cultivation easier and this opportunity was picked up in a massive way by the larger farmers under the increased profitability of farming during the late 1960's. Furthermore, there was a massive subsidy on tractors in the late sixties in Pakistan, raising private returns substantially above social ones. Ease of self cultivation and opportunities for land expansion surely also played a role in India, although predatory farm growth of the type observed in Pakistan was prevented by land ceiling and tenancy laws. Unfortunately, the Indian studies do not generally provide data on farm growth of the tractor farm after tractorization occurred but some scanty evidence of farm growth caused by tractors is available.[45] It nevertheless is clear that tractors shift the cost advantage in farming towards the larger farms and that they therefore induce pressures towards increased concentration of landholdings in fewer hands. This is inconsistent with the stated goal of policy makers in all these countries to achieve a more equal distribution of landholdings.

In India, rising wage and bullock labor costs must also have contributed to the private profitability factor, at least in the late

[44] It must again be stressed that the findings of this survey are not applicable to environments with substantially higher wages and with an open land frontier.

[45] In Jodha's (1974) Rajasthan study, in the most closely examined village, the total area under tenancy or lease or sharecropping increased from 70 ha in 1964-65 to 130 ha in 1973-74. The share of small farmers in total land on lease declined from 54.8 to 11.2%, while tractor-owning farmers increased their share of leased-in land from nil to 76.5% during the same period.

1960s—the period of most rapid tractor investment. Most tractor investment was confined to areas with rising wage rates. This fact is also an indication that rising wage rates, usually perceived as "scarcity" of labor, were increasingly contributing to the private tractor benefits. Of course, farmers cannot always find labor at all times at a fixed wage rate. Additional labor has often to be attracted from outside an area by wage rate rises. If the rises needed are high, farmers may prefer to mechanize, but policymakers might consider policies aimed at improving labor mobility.

Outright subsidies on tractors or interest rates played a lesser role in India than in Pakistan. India even imposes an excise tax on domestically produced tractors.

The benefit-cost studies put no value on *nonagricultural benefits of tractors.* To anyone who has ever worked on a farm it is clear that it is nicer to work with a tractor than without. The often incredible drudgery of farm work is not only reduced for the tractor driver, who usually is the farmer or his son (who might not be interested in bullock driving), but also for the rest of the family.

However, in an environment of stagnant or declining wages, loss of employment may relieve landless laborers of drudgery but it clearly increases rather than reduces their suffering. They have accepted to perform the arduous tasks only because they were forced into them by lack of better alternatives. As long as population growth and slow growth of manufacturing and tertiary sector employment continue to press on rural wages, reducing drudgery is not a social benefit. It simply redistributes benefits from the poorest groups to already richer strata of the rural society.

An additional nonagricultural benefit of the tractor is its use for nonagricultural transport, which provides consumer benefits and sometimes nonagricultural producer benefits. It would be a serious mistake to underestimate these benefits and the extent of nonagricultural uses by tractor owners (Table 12) should convince us that they do value those benefits highly. Nor should we frown on those benefits, as is done by many tractor proponents. After all, the ultimate goal of any production is consumption, and if tractors provide direct consumer benfits, what is wrong with that—as long as it is not at public expense?

It is also clear to most observers that big farmers sometimes invest in tractors and other machines in order to avoid what—in their judgment—are problems of labor management, discipline and supervision, particularly in view of the fact that the high yielding varieties have led to increase labor demand and hence enhanced the bargaining power of laborers in the areas where most tractor investment occurred.

Given the nonagricultural benefits of tractors, tractor investments can occur even if the purely agricultural private net benefits are somewhat below the break-even point, although the rational for public support of the investment disappears. The neglect of these benefits in benefit-cost calculations is unfortunate, but easily explained by the difficulty of estimating them.

The other main conclusion of the surveys relates to the labor-saving nature of the tractor investments. That tractor farms generally do not show much less labor use per hectare than do bullock farms does not imply that they are not labor displacing. What counts is, first, that the frequently higher levels of output on tractor farms (on account of their better capitalization) are generally produced by equal amounts or even less labor. Second, even if the tractor investment left employment unaffected, we must count the foregone employment of not investing the additional capital required for tractors into employment-creating irrigation or even nonagricultural investments as an employment cost of tractors.

Finally, it must be stressed that tractorization of agriculture in the subcontinent has not proceeded very far. It has been confined to the higher wage areas, such as the Punjab, or to the more prosperous coastal areas of Tamil Nadu and Andhra Pradesh. There is no evidence whatsoever that tractors have high benefit-cost ratios in semi-arid zones or even in the eastern rice belt of the subcontinent. Tractorization has further been largely confined to operations such as tillage and transport of all kinds in which either power or running speed give it a substantial comparative advantage. In particular it has not yet been used for a host of highly labor intensive operations such as transplanting or weed control (in conjunction with herbicides). Nevertheless the potential for such uses is there, as are other potential laborsaving innovations such as combine harvesters, threshers, or herbicides. Many of these innovations may be unprofitable or only marginally profitable at present, but may quickly obtain a cost advantage after fairly modest labor cost rises. Taken together, the potential mechanical and chemical labor-savings innovations will ensure a highly elastic labor supply from agriculture should wage rates in the subcontinent start to rise due to vigorous nonagricultural labor demand.

We therefore must expect that, even with rapidly growing labor demands from the nonagricultural sectors, wages for unskilled labor will rise slowly. After wage rises we must expect substantial shifts of private investment by farmers into labor-saving technology. This investment process is likely to generate a series of ceilings on wage rates. At each of these ceilings the agricultural sector will be able to release massive amounts of labor without rapid rises in wage rates.

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APPENDIX—A
A MINIMAL COMMON FRAMEWORK FOR MECHANIZATION RESEARCH

TAKEN together, the literature on tractors in southern Asia shows that fairly simple farm level surveys combined with straightforward analytical tools can provide powerful insights in the productivity and income distribution consequences of agricultural machines at micro-levels. Furthermore, surveys can be structured in such a way that the micro-findings can be meaningfully aggregated to at least regional levels. It should be stressed that, in addition to such agroeconomic surveys, special efforts are now needed to investigate issues connected with the machinery-manufacturing sector and with the effect of mechanization on the laborers affected by them.

THE MINIMUM SCOPE OF THE DATA

A machinery-consequences survey proceeds by identifying regions and subregions where machines have been adopted in sufficient number to make the enquiry meaningful. Within this region, cluster sampling techniques are used to identify villages or groups of villages in which the enquiry will proceed. A census of all households in this cluster is taken, which, in addition to names and addresses, provides those pieces of information required to draw a *stratified random sample* from the household list. This information includes main and subsidiary occupation, size of land holding, irrigation levels, education, machinery ownership or machine use, and any other information which may bcome an *ex ante* stratification variable. Completeness of the census is essential for any later regional aggregation work.

Stratification is then done according to mechanization levels and to land-holding size. If irrigation or other variables vary substantially, and are likely to lead to serious difficulties of interpretation of the results, additional stratifications have to be introduced. It is essential to include a *landless labor sample* in the scheme to estimate the incomes derived by these groups from employment doing agricultural operations—employment which might be lost if these operations are performed mechanically.

For the random sample, the minimum data base includes the following schedules:

1. *Household member schedule*

   Containing demographic educational and occupational data.

2. *Cultivation schedule*

   This schedule will most often be collected in several rounds over one or several years. Information is collected and recalled on a plot basis where plots are contiguous pieces of land planted to the same crop. To be useful in answering timeliness questions, the data must be collected operation-wise with one line on the schedule for each operation. Operations must be dated so that delays and "turnaround" times can be estimated and labor use can be estimated for peak and off-peak periods. If possible, the schedules should be constructed so that they can be analyzed by hand methods and/or directly computerized without transfer to coding sheets.

   The first step in the analysis of the schedules is the field-wise summary of the data, which adds up all inputs and outputs for a season by category.[1] The fieldwise summaries are fairly easy to computerize whereas computerizing and analyzing the raw data is usually a traumatic experience.

3. *Animal care and tractor service schedule*

   The basic purpose is the collection of cost and labor requirement for draft animals and the fixed and variable costs and labor requirements for tractor service and repair including frequency, time, and labor requirement in tractor repair shops.

4. *Asset schedule*

   Contains an inventory of machines, implements, animals and consumer durables. The last item is required for analysis of data by wealth class.

5. *Plot inventory and crop rotation history over the past few years*

   This schedule is crucial to obtain information of the impact of mechanization on cropping patterns, farm growth, and land reclamation. It must be collected for all sample households, including non-mechanized farms and landless laborers, since the landless may have become so only during the past several years. Also, unless the

[1]These summaries are on the basis of the plot and not on a per ha basis, because of the need for aggregation at later stages.

nonmechanized farms arc included, one cannot sort out the question whether changes in cropping pattern were caused by the machines or by common responses to changing prices or new varieties, or whether land reclamation occurred only on mechanized or also on non-mechanized farms.

Attempts can also be made to trace yields over time, but this can quickly become inaccurate. Some information can be collected on the same schedule, such as "when did you first use HYV's or fertilizer or a machine?"

6. *The supplementary income schedule*

Collects data on all wage and nonagricultural incomes. If incomes from animal husbandry are not collected on schedule (3) they have to be collected here. Agricultural labor income has to be disaggregated by task. How many hours of ploughing, weeding, harvesting, threshing; and at what wage rate.

MINIMUM TABULAR ANALYSIS OF THE CULTIVATION SCHEDULE

Cultivation schedules can be analyzed in many ways, but two crucial types of analysis are required:

(a) Timeliness and cost of delays.

The first author producing such tables was A. S. Kahlon (they are partly reproduced in Table 10 of this monograph). It can serve as an example of analyzing the effects of delays in weeding or harvesting as well.

(b) Input-output relationships by farm type/farm size class.

These input-output tables are basic to any further analysis—such as decomposition, benefit-cost analysis, linear programming, quadratic programming, regional projections, regression analysis, etc. They are grouped by crop and can be organized as in Appendix Table 1.

The individual cells in the input-output tables are all physical quantities or values per ha. The subtotals and totals are *values per ha of gross cropped area in a given farm class,* because w, is the share of crop i in gross cropped area. An exception is EiS$_t$Y, where s$_{(}$ is a value aggregate. The tables can be made as complicated as desired. For example one can break out only total tractor labor or break that down into field preparation, interculture, transport and harvesting. One can also distinguish owned bullock and hired bullock hours, and can break down the labor hours by operation. When breakdowns become very fine, it makes sense to split the tables into several subtables. Note that the input-output table can be broken down only to the level of the fieldwise summary discussed earlier. There must be a correspondence of the fieldwise summary with the minimum breakdown of the input-output table.

Appendix Table 1

Input-Output table for Mechanization class X, Strata Q																					
																	Machinery inputs				
										Labor inputs							Tractor				
							Other inputs (value)			Family			Hired								
Crop class	Crop	Area share w_i	Value share s_i	Yield per ha Y_i	Value per ha y_i	Fertilizer per ha value F_i	X_1	X_2	X_3	M L_1	F L_2	C L_3	M L_4	F L_5	C L_6	Other L_7	Land Prep. T_1	Other T_2	Thresher T_3	Bullock B	Other
Fallow																					
Traditional Unirrigated	Sorghum Cowpea etc.																				
Subtotal		$\sum w_i$	$\sum s_i$	$\sum w_iY_i$	$\sum s_iy_i$	$\sum w_iF_i$	$\sum w_iX_{1i}$			$\sum w_iL_{1i}$							$\sum w_iT_{1i}$		$\sum w_iT_{3i}$	$\sum w_iB_i$	
Traditional Irrigated	Rice etc.																				
Subtotal																					
HYV Unirrigated	Sorghum Cotton etc.																				
Subtotal																					
HYV Irrigated	Rice Sugarcane etc.																				
Subtotal																					
Total		$\sum w_i$	$\sum s_i$	$\sum w_iY_i$	$\sum s_iy_i$	$\sum w_iF_i$	$\sum w_iX_{1i}$			$\sum w_iL_{1i}$							$\sum w_iT_{1i}$		$\sum w_iT_{3i}$	$\sum w_iB_i$	

DECOMPOSITION AS A MINIMUM ANALYSIS

Decomposition of output and labor-use differences may be one of the most powerful analytical tools to be used with mechanization survey data. The precise decomposition attempted will depend on the local conditions and on the machines now used on mechanized and nonmechanized farms. The advantages of decomposition over programming, simulation, or regression techniques derive from its computational simplicity because it can be done with a simple calculator. It is essential for benefit-cost studies of the budgeting type which requires attribution of benefits to machines. Finally, it can be understood by people with backgrounds widely diverse in terms of discipline or level of training. It is not competitive with more complex techniques, but these should only be attempted where computer facilities and concentrated analytical man-power make them feasible.[2]

Output Decomposition into Intensity, Yield, and Cropping Pattern Effects. The goal of this decomposition is to split up the output differences observed between farms "with and without" certain machines or "before and after" investment in certain machines into an intensity, yield, and cropping pattern component. Once that is done, one can ask much more precisely how each of these effects may have arisen and whether a particular machine was causal for achievement of the effects. Together with information about differences in irrigation, cropping pattern, and yield-raising investment such as fertilizers, a clear picture of the output effect of a given machine can usually be obtained. In what follows, a mathematical derivation is given in a continuous function framework. Of course, at the farm level observed changes in cropping pattern (for example) are discrete, and the discrete case is discussed later. The following notation is used:

Y_i = yield of crop i P_i = price of crop i

$y_i = Y_iP_i$ = values of crop i per ha (yield in money terms). As in the input-output table, HYV and traditional varieties or irrigated and nonirrigated plots of the same crop are treated as "different crops."

G = gross cropped area

A = operated area

N = net cropped area

F = fallow land = A - N

fallow land will be treated as crop number zero

[2] Decomposition goes back a long way, at least to Minhas' work. It has mostly been used to analyze aggregate time-series data. What is proposed here is to extend the analysis to decomposition across farm types as well.

$c = G/A$ = cropping intensity (alternatively c could be defined as $c^* = G/N$, but the extent of fallow is an important consideration in the mechanization debate in some areas).

A_i = area under crop i

$W_i = A_i/G$ = proportion of gross cropped area under crop i

$y = \sum w_i y_i$ = value of output per operated area. This is the yardstick of "productivity" of a farm class in meeting national production goals.

$s_t = w_i y_i / y.$ = value share of crop i in total value.

The decomposition of total output q goes as follows:

$$q = cy. = c \sum_i w_i y_i$$

Differentiating totally

$$dq = dc \sum_i w_i y_i + c \sum_i w_i dy_i + c \sum_i dw_i y_i \qquad \text{(II)}$$

This equation can be converted into *rates* of charge or proportional charge by:

—dividing both sides of the equation by. q

—dividing and multiplying the second and third right hand side term of equation II by y_t and w, respectively.

$$\frac{dq}{q} = \frac{dc \sum w_i y_i}{c \sum w_i y_i} + \frac{c \sum_i w_i y_i dy_i}{c \sum_i w_i y_i y_i} + \frac{c \sum_i w_i y_i dw_i}{c \sum_i w_i y_i w_i}$$

After cancelling, we get the following expression

$$\underset{}{\frac{dq}{q}} = \underset{(a)}{\frac{dc}{c}} + \underset{(b)}{\sum_i s_i \frac{dy_i}{y_i}} + \underset{(c)}{\sum_i s_i \frac{dw_i}{w_i}} \qquad \text{(III)}$$

The three right hand side terms measure the contribution to the proportional difference in output per ha of operated area of (a) intensity, (b) yield, and (c) cropping pattern changes. The yield effect (a) is the share-weighted sum of the yield differences of individual crops and the cropping pattern effect, (b), is the share weighted effect of the cropping pattern differences.

When converting this equation into discrete effects, the following notation is adopted. Let A and B be two different farm types or one farm type "before and after" acquisition of a machine.

Let X_A and X_B the levels of any measured variables in the two farm types and define the proportional differences,

$$X' = \frac{X_A - X_B}{\hat{X}} = \frac{\Delta X}{\hat{X}}$$

where $\bar{X} = (X_A + X_B)/2$, i.e. the mean of the variable among the two types.[3] (Note that geometric means could be used instead of arithmetic means—i.e. $\bar{X} = \sqrt{X_A X_B}$). Thus equation III can be rewritten as follows:

$$q' = c' + \sum_i \bar{s}_i y_i' + \sum_i \bar{s}_i w_i' + R \qquad \text{(IV)}$$

The R term is a "residual" or "interaction" effect which can be given alternative interpretations. It is usually small and I prefer to regard it simply as approximation errors arising out of the switch from the continuous to the discrete case. It can be measured, and if too large relative to the other terms, helps provide a check on spurious effects. The output decomposition is computed from and displayed in Appendix Table 2 which corresponds closely to the two input-output tables of the two farm types compared.

A decomposition table displayed in this fashion can give very clear indications of the most important source of output differences. If it is intensity, irrigation data can be compared to see if the irrigation difference is larger or smaller than the intensity differences. Large yield contributions can be compared with fertilizer levels to see if it is machine or fertilizer that is the predominant source of the yield difference. And large cropping patter effects can be compared to capital and machine input data to see whether or not the cropping pattern difference was conditional on the machine. If a farmer plants more maize after acquiring a maize planter, the machine was casual, but if output on tractor farms is higher because they plant more tobacco, it is hard to believe that the tractor was an essential precondition for the shift. Interpretation of these tables requires common sense and knowledge of the farming situation in the area, but they include no complicated techniques which are the exclusive preserve of a single discipline.

THE DECOMPOSITION OF LABOR USE FOR A SINGLE CROP

Raj Krishna (1976) has shown how to decompose the labor-use effect of several layers of interacting technologies into the effects of single components. His article also shows how to generalize that approach to many crops and, as a last step, how to integrate the findings with standard interindustry input-output tables to get at the indirect employment effect of agricultural technical changes in other sectors of the economy. This set of methodologies can be used in a

[3] It is important to measure proportional differences with respect to average levels to keep approximation errors [the R term in equation (IV)] low.

APPENDIX TABLE 2

Output Decomposition for Farm Types A and B								
Productivity difference: $q' =$		Intensity difference $c' =$			Irrigation difference $I' =$			Education difference $E' =$
Crop class	Crop	Value share $\bar{s}_i$	Area share w_i	Yield effects $s_i y_i'$	C pattern effects $s_i w_i'$	Fertilizer diff. F_i'	Other input diff. X_1' X_2' X_3'	etc.
Fallow								
Traditional Unirrigated	Sorghum Cowpea etc.							
Subtotal		$\sum \bar{s}_i$	$\sum \hat{w}_i$	$\sum \hat{s}_i y_i'$	$\sum \hat{s}_i w_i'$	$\sum \hat{w}_i F_i'$	$\sum \hat{w}_i X_i'$	....
etc.								
HYV Irrigated	Rice Sugarcane etc.							
Subtotal								
Total				$\sum \hat{s}_i y_i'$	$\sum \hat{s}_i \hat{w}_i'$	$\sum \hat{w}_i F_i'$	$\sum \hat{w}_i X_i'$	....

step-wise fashion. Below, the principle of labor decomposition will be shown in a simplified example for a single crop.

Operations can be divided into those where labor input is (a) *area dependent* or (b) *yield dependent.* Let us consider only two, namely ploughing as type (a) and threshing as type (b). If all other operations are performed in the same way on two farm types or "before and after," they can simply be neglected. The following notation is used:

t = proportion of area ploughed by tractor
s = proportion of output threshed by thresher
Note that s and t are equal only in exceptional circumstances.
u_T = labor per ha ploughed by tractor (operators)
u_B = labor per ha ploughed by bullock
v_R = labor per quintal threshed by thresher
v_H = labor per quintal threshed by hand
Y_T = yield per ha on area ploughed by tractor
Y_B = yield per ha on area ploughed by bullock
$Y.$ = average yield per hectare

Then $Y. = tY_T + (1 - t)Y_B$ (V)

and labor use L for ploughing and

$L = tu_T + (1 - t)u_B + sv_RY. + (1 - s)v_HY.$ (VI)

Holding all labor coefficients v and u constant and differentiating (VI) and (VII) totally in succession and aggregating terms leads to the following equation:

$$\begin{aligned} dL &= (u_T - u_B)dt && \text{(a)} \\ &+ sv_R + (1 - s)v_H(Y_T - Y_B)dt && \text{(b)} \qquad \text{(VII)} \\ &+ (v_R - v_H)y.ds && \text{(c)} \end{aligned}$$

Part (a) and (b) together are the effect of increasing the proportion of area under tractor. The (a) part is the direct effect of tractor ploughing on the tractor operator and bullock driver. Part (b) is the indirect effect of tractor ploughing on threshing labor which occurs if tractor ploughing increases yields (in the case of tractors, the yield difference is often zero so that this term disappears, but if irrigation were considered, the effect might be large). The (c) term is the thresher effect which traces how much labor is displaced by the thresher.

Equation (VII) can be translated into discrete terms by replacing dt and ds by At and As and by replacing s by $s = (s_A + s_B)/2$ in the (b) term. Unlike the output decomposition, transformation into proportional differences is not straightforward but it can be done once all absolute effects are computed numerically.

Krishna's example is much more complex and considers two varieties, three irrigation levels, and bullock and tractor farms. For individual country studies, the decomposition will have to be worked out depending on the local condition, but the derivations are straightforward. If desired, whole farms can be considered by computing the labor decomposition for all crops—i.e. computing the full set of dLi and its components. The total labor effect of all changes are then computed as follows, where L. is total labor use on the farm

$$dL. = \sum_i w.dL, \qquad \text{(VIII)}$$

For individual components such as the tractor ploughing effect, similar share-weighted sums can be computed as time and resources permit.

REGIONAL AGGREGATION AND PROJECTION OUTPUT AND LABOR EFFECTS

If clustered stratified random sampling techniques have been used, regional aggregation and projection is straightforward and proceeds directly from the decomposition analysis. Rates of additional machinery investment can be assumed or projected from past data and translated into regional At and As projections. They can be combined with regional benefit-cost analyses. Normative frameworks such as linear, dynamic, or integer programming can also be used since the decomposition analysis presupposes knowledge of all coefficients required for these exercises. Computation of indirect employment effects outside agriculture presupposes the existence of sufficiently disaggregated input-output tables and of expenditure elasticities of incremental income.

APPENDIX—B

TRACTOR INVESTMENT AND TRACTOR POLICIES IN INDIA

Domestic production, imports, and total availability of tractors (Table B-l) indicate a slow rise of tractor investment up to 1965-66, a rapid rise between 1966-67 and 1970-71, with a peak of 32,041 tractors in 1970-71. Thereafter investment declines to only 25,000 in 1973-74 and jumps back again to about 33,000 between 1974-75 and 1976-77.

From 1964-65 onwards, domestic production exceeds imports in most years. Imports decline from 4,000 in 1967-68 to zero in 1976-77. But between 1970-71 and 1972-73, imports jump massively to an average of more than 8,000 per year for the 3-year span. Reasons for this are explained in Table B-2. Prior to 1971, tractors were exempt from import tax. In 1971 a 30-percent tax rate plus a 10% excise duty was imposed. However, at the same time a gift scheme was in operation which continued up to 1973.

Under the gift schemes, relatives or friends residing abroad paying in foreign currency could send a tractor to a farmer in India exempt of all import and sales taxes. This explains the tremendous import activity between 1970 and 1973; in 1973, the scheme was stopped and all imports were banned.

The excise tax imposed on tractors by the Central Government has been 10 percent since 1972. Note that this is *lower* than the excise tax on fertilizers (and some other agricultural inputs) which started at 10 percent in 1969 and was raised to 15 percent in 1972. The excise tax is therefore not discriminating against tractors. The excise duty is levied on the ex-factory price, while the central sales tax is levied on the retail price at a rate of 3 percent until 1973, and 4 percent from 1974 onwards. This tax, a general revenue tax, is not discriminating against tractors. State sales taxes now vary from 1 to 9 percent, depending on the state. As shown in footnote (c) to Table B-2, the

TABLE B-1. *Import and Domestic Production of four wheel tractors.*

YEAR	Domestic* Production	Imports[b]	Total Availability	Nominal Price"' Index Base 1965	Real Price[d] Index Base 1965
61-62	880	2997	3877		
62-63	1414	2616	4030		
63-64	1983	2349	4332		
64-65	4323	2323	6646		
65-66	5714	1989	7703	100.00	100.00
66-67	8816	2591	11407	118.78	106.10
67-68	11394	4038	15432	132.30	102.73
68-69	15437	2508	17945	133.39	104.01
69-70	18120	304	18424	134.14	102.43
70-71	20009	12032	32041	134.14	96.48
71-72	18100	9917	28017	143.57	99.44
72-73	20802	3077	23879	165.86	106.52
73-74	24425	574	24999	168.56	90.69
74-75	31088	652	33740	200.75	84.93
75-76	33252	2	33252	265.11	110.52
76-77	33146	—	33146		

Source: [a] **Indian Society of Agricultural Engineers, Farm Machinery Directory, 1977-78.**

[b] **Mr. P.J. Zacharia, Personal communication on the basis of monthly statistics of Foreign Trade of India, vol. 2.**

[c] **Mr. P.J. Zacharia, Machinery Division, Ministry of Agriculture and Irrigation.**

[d] **Based on wholesale price index of all commodities. Bulletin of food statistics, Government of India.**

TABLE B-2: Tax Policies on Tractors, Fuels and Fertilizers

Year	Exise duty on ferti- lizers	Excise duty on Factory price of Tractors"	Import Duty on Tractors	Central Sales Tax on Retail Price of Tractors	Slate Sales Tax on Retail Price of Tractors	Import duty on diesel fuel	Excise duty on diesel fuel (Rs. per kilo-litre)
1969	10%	0	0	3%	N.A.	100%	N.A.
1970	10%	0	0	3%	N.A.	100%	287.70
1971	10%	0	30%[b]	3%	1/2 to 9%[c]	100%	287.70
1972	15%	10%	30%[b]	3%	1/2 to 9%[c]	100%	287.70
197S	15%	10%	Ban on imports	3%	1/2 to 9%[c]	100%	329.00
1974	15%	10%		4%	1 to 9%	100%	329.00

N.A.: Not available.

sales tax is lowest in the Punjab where most of the tractor investment is concentrated—the rate is only 1 percent. In general the sales tax seems to be lower in those states with heavy tractor investment. Tractor fuels have been taxes at a 100-percent rate throughout the period.

This tax is again not discriminatory, as it applies equally to all diesel fuel, regardless of its use. Finally, there are some minor taxes on imports of tractor components which are not produced domestically, but their total effect is smaller than any of the taxes discussed so far.

The sharp fluctuations in total tractor availability after 1971 (a proxy for sales) appears to be primarily a reflection of the changes in import policy and the impact of higher fuel prices after the formation of an effective OPEC cartel. Real prices of tractors in terms of agricultural commodities shows no definite trend between 1965-66 and 1975-76.

In Table B-3, the all-India tractor stocks for the agricultural census years and the breakdown by states are given. In addition, tractor densities per 1000 ha of gross cropped area are presented.

It is clear that by 1972 tractorization (with a total stock of about 148,000) had not proceeded very far. Tractors are heavily concentrated in the Punjab, western Uttar Pradesh, and Haryana. Tractor densities give an even better picture of the regional concentration.

The ranking according to tractor densities clearly corresponds to the extent in which a state has benefited from the green revolution—Punjab, Haryana, Uttar Pradesh, Gujarat, Tamil Nadu, Rajasthan, etc. Andhra Pradesh benefited more from the green revolution than

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Source: a) P. J. Zacharia, Cost Reduction of Mechanization Input for Improving Agricultural Production, Machinery Division, Ministry of Agriculture and Irrigation, New Delhi, January 1976.
Also personal communication by Mr. Zacharia.
Excise duty on power tillers was set at 15% and was withdrawn on December 2, 1977 (Economic Times, December 3, 1977).

b) In addition, an excise duty of 10% on landed cost was imposed. From 1971 to 1973, a gift scheme was in operation which allowed the import of tractors free of all taxes and duties, provided the foreign exchange was paid for by relatives residing abroad.

c) In 1975 the State Sales Taxes on tractors for selected states were as follows: Punjab 1%; Haryana 4%; Delhi and Rajasthan 5%; Andhra Pradesh, Gujarat, West Bengal, Uttar Pradesh 6%; Bihar, Kerala 7%; Maharashtra, Madhya Pradesh, Orissa 8%; Tamil Nadu *9%;* Sales Taxes were therefore the lowest in those States which accounted for the bulk of tractor sales.

d) Indian Customs and Central Excise Tariffs, Vol. I and II.

its rank 11 implies, but the green revolution was concentrated in a few coastal districts with the rest of the state hardly benefiting at all.

TABLE B-3: Four-wheel tractors used for agricultural purposes in India

all India

1945	..	4,500
1951	..	8,600
1956	..	21,000
1961	..	31,000
1966	..	54,000
1972	..	1 48,300

by States

State	1961	1966	1972	Tractor density (no/1,000 ha) during 1972	Rank based on density
Andhra Pradesh	1,762	2,911	6,300	.4979	11
Assam	489	834	500[b]	.1764	15
Bihar	1,520	2,132	5,600	.5242	8
Gujarat	2,005	3,284	7,900	.7953	4
Haryana"		4,850	18,400	3.645	2
Himachal Pradesh	4	33	300		
Jammu & Kashmir	132	104	500	.5773	7
Karnataka	981	2,295	5,700	.5187	9
Kerala	276	418	1,500	.5071	10
Madhya Pradesh	2,025	2,513	5,000	.2393	14
Maharashtra	1,427	3,274	5,600	.3203	12
Orissa	194	667	1,800	.2556	13
Punjab[a]	7,866	10,646	42,400	7.407	1
Rajasthan	3,196	4,195	11,700	.6975	6
Tamil Nadu	1,387	3,278	5,400	.7083	5
Uttar Pradesh	7,139	10,139	27,600	1.19	3
West Bengal	330	1,548	700	.0963	16
Union Territories	283	702	1,400		

Source: Various Issues of Statistical Abstracts of India.
[a]Haryana included in Punjab (undivided) in the year 1961.
[b]Assam has been split into several states between 1961 and 1971.

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