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Precision Farming Technology, Adoption Decisions and Productivity of Vegetables in Resource-Poor Environments

R. Maheswari, K.R. Ashok* and M. Prahadeeswaran
Department of Agricultural Economics, Tamil Nadu Agricultural University, Coimbatore - 641 003, Tamil Nadu

Abstract

'Precision Farming' or 'Precision Agriculture' aims at increasing productivity, decreasing production costs and minimizing the environmental impact of farming. In this context, the present study has been undertaken to understand the impact of precision farming on resource-poor regions and underprivileged farmers. Specifically, the study has looked into productivity, income, employment, and adoption behaviour of technology in agriculture. The study, conducted in the Dharmapuri district, has collected data on precision and non-precision farmings through the interview schedule during the year 2007. Sources of the productivity difference between the precision and conventional farmings have been identified by decomposing the productivity change. Financial impact of adoption has been studied through a two-stage econometric model. The first stage of the model consists of an adoption decision model that describes the factors which influence the likelihood of adopting precision farming. Results of first stage have provided input for the second stage of the model, which has been used to estimate the impact of precision farming on farm financial performance. The study has revealed that adoption of precision farming has led to 80 per cent increase in yield in tomato and 34 per cent in brinjal production. Increase in gross margin has been found as 165 and 67 per cent, respectively in tomato and brinjal farming. The contribution of technology for higher yield in precision farming has been 33.71 per cent and 20.48 per cent, respectively in tomato and brinjal production. The elasticity of 0.39 for the adoption in tomato and 0.28 in brinjal has indicated that as the probability of adoption increases by 10 per cent, net return increases by 39 per cent and 28 per cent in tomato and brinjal cultivation. Lack of finance and credit facilities have been identified as the major constrains in non-adoption of precision farming. The study has suggested that providing of subsidies for water-soluble fertilizers and pump-sets will increase adoption of precision farming.

Introduction

The share of agriculture in the gross domestic product has registered a steady decline, from 36.4 per cent in 1982-83 to 18.5 per cent in 2006-07. But, the agricultural sector continues to support more than half a billion people providing employment to 52 per cent of the workforce. The growth in agriculture over a period of time has remained lower than the growth in non-agriculture sector and this decelerating trend is a cause of concern. The gap between growth in agriculture and non-agriculture sectors began to widen in 1981-82, and more particularly, since 1996-97, because of acceleration in the growth of industry and services sectors (Economic Survey, 2008). Notably, the agricultural growth performance could not be sustained during the 1990s because of decelerations in yield and output growth rates in both food and non-food crops. A comparison of the decadal growth in area, production and productivity of food grains since 1950s reveals that India has been experiencing stagnation or negative growth in these crops. Increasing agricultural productivity perhaps remains the single most important determinant of

* Author for correspondence,
E mail: ashok10tnau@yahoo.com

economic growth and poverty reduction, and hence provides the key to millennium development goal. Improvements in productivity come from adoption of new technologies and increase in production efficiency. 'Precision farming' or 'Precision Agriculture' aims at increasing productivity, decreasing production costs and minimizing the environmental impact of farming. The management of in-field variability in soil fertility and crop conditions for improving crop production and minimizing the environmental impact is the crux of precision farming. New technologies, such as Global Positioning Systems (GPS), sensors, satellites or aerial images, and Geographical Information Systems (GIS) are utilized to assess and analyse variations in agricultural production.

In Tamil Nadu, precision farming was implemented under the Tamil Nadu Precision Farming Project (TNPFP) in the Dharmapuri and Krishnagiri districts on about 400 ha of land with a total budget of 720 lakhs for a period of three years. The scheme was extended to six more districts in 2005-06. Most parts of the Dharmapuri and Krishnagiri districts are semi-arid tracts with low rainfall and low productivity. In this context, the present study was undertaken to understand the impact of technological innovations like precision farming on resource-poor regions and underprivileged farm households. Specifically, the study has looked into the productivity, income, employment, and adoption behaviour of the technology in agriculture.

Methodology

The study was conducted in the Dharmapuri district and data on precision and non-precision farmings were collected through the interview schedule during the year 2007. The respondents were selected randomly from the five identified blocks in such a way that there were 35 adopters and 35 non-adopters of precision farming in each of tomato and brinjal crops, making the total sample to be of 140 respondents.

Differences in productivity, income and employment under the precision and conventional farmings were worked out from the cost cultivation data. Sources of the productivity difference between the precision and conventional farmings were identified by decomposing the productivity changes, following Bisaliah (1977). Cobb-Douglas production functions, for precision and non-precision farmings were fitted as follows:

$$\ln Yp = \ln bp_0 + bp_1 \ln SEEDp + bp_2 \ln MANUREp + bp_3 \ln LABOURp + bp_4 \ln PPCp + bp_5 \ln IRRIGATIONp + bp_6 \ln Np + bp_7 \ln Pp + bp_8 \ln Kp + Up \quad \ldots(1)$$

$$\ln Ynp = \ln bnp_0 + bnp_1 \ln SEEDnp + bnp_2 \ln MANUREnp + bnp_3 \ln LABOURnp + bnp_4 \ln PPCnp + bnp_5 \ln IRRIGATIONnp + bnp_6 \ln Nnp + bnp_7 \ln Pnp + bnp_8 \ln Knp + Unp \quad \ldots(2)$$

where,

SEED	= Seed rate in grams per ha
MANURE	= Manures in kg per ha
LABOUR	= Total labour in humandays per ha
PPC	= Total plant protection chemical in grams per ha
IRRIGATION	= Irrigation water (ha-cm)
N	= Total nitrogen in kg per ha
P	= Total phosphorus in kg per ha
K	= Total potash in kg per ha
bi	= Parameters to be estimated
u	= Random-error term
Subscript p	= Precision farming
Subscript np	= Non-precision farming

Taking differences between Equations (1) and (2), adding and subtracting some terms and on rearranging these terms, one gets Equation (3):

$$\ln (Y_p/Y_{np}) = \{\ln (b_{p0}/ bnp_0)\} + \{(b_{p1} - b_{np1}) \ln SEEDnp + (b_{p2} - b_{np2}) \ln MANUREnp + (b_{p3} - b_{np3}) \ln LABOURnp + (b_{p4} - b_{np4}) \ln PPCnp + (b_{p5} - b_{np5}) \ln IRRIGATIONnp + (b_{p6} - b_{np6}) \ln Nnp + (b_{p7} - b_{np7}) \ln Pnp + (b_{p8} - b_{np8}) \ln Knp\} + \{b_{p1} \ln (SEED_p/SEED_{np}) + b_{p2} \ln (MANUREp/ MANURE_{np}) + b_{p3} \ln (LABOURp/LABOURnp) + b_{p4} \ln(PPCp/PPCnp) + b_{p5} \ln (IRRIGATIONp/IRRIGATIONnp) + b_{p6} \ln (Np/Nnp) + b_{p7} \ln (Pp/Pnp) + b_{p8} \ln (Kp/Knp)\} + [(U_2 - U_1)] \quad \ldots(3)$$

The LHS of Equation (3) denotes the difference in per hectare productivity of precision and non-precision methods, while the RHS decomposes the difference in productivity into the changes due to technology as well as input-use. Equation (3) has three major terms on RHS. These respectively refer to (i) gap attributable to neutral technological change, (ii) gap attributable to non-neutral technological change, and (iii) change due to input-use.

The financial impact of adoption was studied through a two-stage econometric model. To control factors for other than precision farming adoption, multiple regression was used in a two-stage econometric model of adoption and the adoption impact. The first stage of model consisted of an adoption decision model that described the factors which could influence the likelihood of adopting precision farming. The results of first stage provided the input for the second stage of model which was used to estimate the impact of precision farming on farm financial performance. This two-step approach was similar to the approach set forth by Fernandez-Cornejo *et al* (2002) in their study on the impact of the adoption of GE crops on farm's financial performance. In this study, the first stage of Hickman's technique involved the estimation of a precision farming adoption model using the Probit analysis. Estimated parameters from the Probit model were then used to calculate the predicted probabilities ($\hat{P}$) of adopting the precision farming technology. Addressing the simultaneity and self-selectivity concerns when estimating farm net returns was accomplished by appending to the basic regression explaining financial performance the predicted probabilities ($\hat{P}$) of adopting precision farming technology and the inverse mill ratio ($\hat{\gamma}$) as additional regressors, i.e.

$$\Pi_i = \beta_0 \Sigma \beta_j X_{ij} + \gamma_1 \hat{P}_{i1} + \varsigma_{i1} \hat{\lambda}_{i1} + \varepsilon_i$$

where,

Π = A vector denoting net returns

X_{ij} = A matrix of exogenous variables affecting the farm's financial performance

X_1 = Educational status

X_2 = Farming experience

X_3 = Farm-size

X_4 = Extension agency contact (No. / month)

X_6 = Risk-orientation

X_7 = Family labour

X_8 = Non-farm income

$\hat{P}$ = Predicted probability

$\hat{\gamma}$ = Inverse mill ratio, and

ε_i = A vector of errors.

The adoption decision model was estimated by Probit analysis. The model was specified using variables that have been shown to be related to technology choice in the literature (Pindyck and Rubinfeld, 1998; Kiresur *et al.,* 1999). Variables regressed against the decision to adopt each technology included operator's education, experience, farm-size, extension agency contact, risk perception, number of family labour and non-farm income. Operator's preference towards the risk was specified using a risk index, constructed according to farmers' answers to a series of survey questions about how they react towards risk. The adoption-impact model was estimated by regressing the same set of explanatory variables, plus the information obtained from the decision model on farm's financial performance. The farm's financial performance was measured by the net income per hectare. Income was taken as the difference between gross value of crop production and total cost of cultivation. Constraints in adoption of precision farming were ranked by Garrett ranking technique.

Results and Discussion

Economics of Production under Precision and Non-precision Farmings

Economics of tomato production were estimated for precision and non-precision methods of cultivation and the results are presented in Table 1.

The share in total variable cost in the case of precision farmers was highest for fertilizer (27.15%), followed human labour (25.04%). Within the cost on human labour, 72.21 per cent was paid out to hired labour and the rest was imputed value of family labour. In non-precision faming, plant protection chemical was found to be the major input, accounting for 31.06 per cent of the total cost, followed by human labour (25.47%), fertilizer (9.70%) and seedlings (7.90%). The gross margin calculated as

Table 1. Economics of tomato production under precision and non-precision farming

(Rs/ha)

Sl No.	Particulars	Precision farming	Non precision farming	Difference (per cent)
1	Human-labour	25,693	18,382	39.77
		(25.04)	(25.47)	
2	Machine power	6,000	5,250	14.28
		(5.84)	(7.27)	
3	Seedlings	5,100	5,700	-10.52
		(4.97)	(7.90)	
4	Manures	7,292	4,000	82.30
		(7.10)	(5.54)	
5	Plant protection chemicals	9,410	22,420	-58.02
		(9.17)	(31.06)	
6	Fertilizers	27,858	7,004	297.73
		(27.15)	(9.70)	
7	Stacking	5,666	4,700	20.56
		(5.55)	(6.51)	
8	Drip system	8,850	0	100.00
		(8.62)	(0.00)	
9	Interest on working capital @ 7 per cent	6,710	4,721	42.15
		(6.54)	(6.54)	
10	Total variable cost	1,02,581	72,178	42.15
		(100.00)	(100.00)	
11	Main product (kg/ha)	78,663	43,662	80.16
12	Gross returns	4,32,649	1,96,480	120.20
13	Gross margin	330,068No.	124,302	165.54

Note: Figures within the parentheses indicate percentages to total variable cost

the difference between the gross return and variable cost, was 166 per cent higher in precision than non-precision farming in tomato cultivation.

The economics of brinjal production under precision and non-precision methods have been presented in Table 2.

Labour cost accounted for the highest share in total variable cost in precision farming and it was 49.57 per cent more than that of non-precision farming. The cost of fertilizer was the second highest, with 151.66 per cent more in precision farming, mainly due to the high cost of water-soluble fertilizers. Non-precision farmers spent 123.64 per cent higher cost on plant protection chemicals because of high use of these chemicals. The spendings on seedlings, machine power and manures were more are less the same in both the cases. The precision farmers incurred a total cost of Rs 1,10,900/ha, which was 25.47 per cent higher than by non-precision farmers, but realized 77.61 per cent higher net return over non-precision farmers. The gross margin calculated as the difference between the gross return and variable cost, was 67 per cent higher in precision than non-precision farming in brinjal cultivation.

Nature of Technological Change and Sources of Difference in Yield

The homogeneity of production function under both precision and non-precision technologies was tested using dummy variables (Gujarati, 2003). The coefficient of dummy variable was statically significant for both tomato and brinjal crops. It was

Table 2. Economics of brinjal production under precision and non-precision methods of cultivation

(Rs/ha)

Sl No.	Particulars	Precision farming	Non-precision farming	Difference (per cent)
1	Human labour	38,668 (34.86)	25,853 (29.25)	49.57
2	Machine power	6,000 (5.41)	5,340 (6.04)	12.00
3	Seedlings	4,800 (4.32)	5,100 (5.77)	-6.25
4	Manures	6,031 (5.43)	5,975 (6.76)	0.93
5	Plant protection chemicals	13,441 (12.12)	30,061 (34.01)	-123.64
6	Fertilizers	25,853 (23.31)	10,273 (11.62)	151.66
7	Drip system	8,850 (7.98)	0 (0.00)	100.00
8	Interest on working capital @ 7 per cent	7,685 (6.54)	5,782 (6.54)	32.92
9	Total variable cost	1,10,900 (100.00)	88,386 (100.00)	25.47
11	Main product	77,626	57,928	34.00
12	Gross returns	3,50,633	2,31,714	51.32
13	Gross margin	239,732	143,327	67.26

Note: Figures within the parentheses indicate percentages to total variable cost

concluded that the two production functions were not homogenous. The estimates of production functions for tomato and brinjal crops under precision and non-precision farmings are presented in Annexures I and II, respecstively and the geometric means of inputs are given Annexure III. The productivity difference between the precision and non-precision productions was decomposed into its constituent sources and the results are presented in Table 3.

A perusal of Table 3 reveals that the total productivity difference between precision and non-precision farmings of tomato was 63.86 per cent. Among various sources responsible for total productivity variation, the contribution of technology was higher at 33.71 per cent. The contribution due to differences in input-use level was 30.15 per cent. Among various inputs contributing to the productivity difference in precision farming, labour (1.47%), plant protection chemicals (0.16%), phosphorous (54.47%) and potassium (22.79%) contributed positively, whereas seed (-6.12%) and manure (-27.42%), water (-2.67%), and nitrogen (-12.54%) contributed negatively. The productivity difference between the precision and non-precision farming of brinjal was estimated at 28.14 per cent. Among the various sources responsible for total productivity variation, the contribution of technology was highest at 20.48 per cent. The contribution due to difference in input-use levels was 7.68 per cent. Among various inputs contributing to the productivity difference between precision and non-precision brinjal production, seed (0.47%), manure (15.39%) labour (0.19%) and plant protection chemicals (18.32%) contributed positively, whereas water (-0.02%), nitrogen (-2.07%) phosphorus (-11.52%) and potassium (-13.07%) contributed negatively.

Table 3. Decomposition of the productivity difference in precision and non-precision farmings

Source of productivity difference	Contribution, %	
	Tomato	Brinjal
Total difference in output	63.86	28.14
Sources of contribution		
Output difference due to technology	33.71	20.48
Input-use		
Seed rate (kg)	-6.12	0.47
Manures (tonnes)	-27.42	15.39
Labour (humandays)	1.47	0.19
Plant protection chemicals (gram)	0.16	18.32
Irrigation (ha-cm)	-2.67	-0.02
Nitrogen (kg)	-12.54	-2.07
Phosphorous (kg)	54.47	-11.52
Potassium (kg)	22.79	-13.07
Output difference due to input-use	30.15	7.68

Adoption and Financial Impact of Adoption

Financial impact of adoption was studied through a two-stage econometric model. The results are presented in Table 4. In the first stage, predicted probabilities of adoption were estimated through probit analysis. In the second stage, predicted probabilities were used to estimate the financial impact.

The financial impact model, apart from other independent variables, included inverse mill ratio and predicted the probability of adoption from the Probit model. The net return of tomato farming was the dependent variable. R-square was 61.07 per cent and t-tests indicated that the estimate of inverse mill ratio was statistically equal to zero. This means that estimate of the precision farming adoption decision was not biased by non-controllable variables, and hence, it was not overestimated (Key and Warning, 2002). Coefficient of farm-size, extension agency contact and non-farm income were significant and hence, influenced the net return in tomato. Increasing farm size, extension agency contact and non-farm income by one unit will increase the net return by Rs 1293/ha, Rs 8242/ha and Rs 1129/ha, respectively. In the case of brinjal, R-square in the financial impact model was 55.54 per cent. Parameter t-tests indicated that the estimate of inverse mill ratio in the regression model was statistically equal to zero. The significant and positive estimate of farming experience and non-farm income stresses the importance of these variables on net income in brinjal cultivation. Increasing farming experience, non-farm income by one unit will enhance net return by Rs 1542/ha, and Rs 1680/ha, respectively. To illustrate the impact of adoption on net return, elasticities were estimated for the predicted probability. The elasticity of 0.39 and 0.28 for adoption in tomato and brinjal, respectively indicated that as the probability of adoption increases by 10 per cent, net return increases by 39 per cent in tomato and 28 per cent in brinjal cultivation.

Constraints in Adoption of Precision Farming

Reasons for non-adoption of precision farming as ranked by the farmers, were analyzed through Garrett's ranking technique and the results are presented in Table 5.

The results showed that the lack of finance and credit facilities were the most important reasons for non-adoption of precision farming. Obtaining credit was a difficult process, because farmers could not produce collateral security. Drip installation and use of water-soluble fertilizers were very expensive and required credit. Because of output price fluctuations, farmers were not ready to make investments. Lack of knowledge about precision farming technologies was another important constraint, because a majority of small farmers were illiterate and were not able to follow and adopt latest technologies. Labour scarcity was also a problem in adopting precision farming. Due to urbanization and migration, there was a scarcity of labour for agricultural operations. Since precision farming was highly labour-intensive technology and operations were time-bound, farmers faced the dearth of labour, especially during stacking and harvesting.

The traditional farmers had a wrong perception about the higher yield from the précised quantity of inputs. It was a major constraint to the adoption of precision farming. It was found that besides adequate quantum of water for the entire crop duration, and pumping efficiency of motor should also be about 12000 litres of water per hour, with 1.5 kg pressure

Table 4. Financial impact model in tomato and brinjal production

Variable	Tomato	t-value	Brinjal	t-value
Intercept	45.738	1.598	-3.067	-0.088
Educational status (years)	1.899	1.218	0.469	0.278
Farming experience (years)	-1.032	-1.443	1.542**	2.012
Farm size (ha)	1.293**	2.560	3.270	1.240
Extension agency contact(No. / month)	8.242*	2.183	-9.794**	-2.166
Risk-orientation	-0.637	-0.613	0.694	0.592
Family labour	0.176	0.026	-11.267	-1.520
Non-farm income	1.129**	2.609	1.680**	2.565
IMR(Inverse Mill Ratio)	-1.6E+11	-0.643	-1.6E+12	-0.464
Predicted probability	60.738**	2.508	81.396**	2.745
R-square	0.610	—	0.555	—
Elasticity	0.398	—	0.285	—

Note: Figures within the parentheses denote t-values

Table 5. Reasons for adoption and constraints to adoption of precision farming

Reasons	Mean Garrett's score	Rank
Lack of finance and credit facilities	73	1
Drip installation and water-soluble fertilizers are expensive	65	2
Lack of knowledge about precision farming technologies	54	3
Labour scarcity	53	4
Farmers' perception on yield impact of low quantity of inputs	51	5
Lack of water availability and pumping efficiency	44	6
Lack of technical skill to follow precision farming recommendations	42	7
Market tie-ups lead to low price fixation for the produce / unprofitable negotiations	41	8
Inadequate training and demonstrations and weak research – extension – farmer relationship	41	9
Inadequate size of landholdings for adoption of precision farming	27	10

for fertigation in precision farming. Lack of water availability and pump efficiency, lack of technical skill, inadequate size of landholding, mind set, and traditional beliefs were constraints to adoption of precision farming. The local market was not big enough to market the huge quantity of output produced through precision farming, so farmers had to negotiate with supermarkets, etc., but sometimes it led to low price and less profit.

Conclusions

The study has revealed that adoption of precision farming leads to about 80 per cent increase in yield in tomato and and 34 per cent in brinjal. Increase in gross margin has been found 165 per cent and 67 per cent in tomato and brinjal production, respectively. The contribution of technology for higher yield in precision farming has been recorded as 33.7 per cent and 20.5 per cent, respectively in tomato and brinjal. The elasticity of 0.39 for the adoption in tomato and of 0.28 in brinjal indicated that as the probability of adoption increases by 10 per cent, the net return increases by 39 per cent and 28 per cent in tomato and brinjal cultivation, respectively. Lack of finance and credit facilities have been identified as the major constraints for non-adoption of precision farming. The study has suggested that providing of subsidies for water-soluble fertilizers and pump-sets will increase the adoption of precision farming.

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Annexure I

Production function estimates for tomato

Explanatory variables	Regression coefficients		
	Precision farming	Non-precision farming	Pooled with intercept dummy
Seed rate (g/ha)	0.2128	0.3552	0.2400
	(1.0919)	(1.4393)	(1.2270)
Manures (t/ha)	-0.0715	-0.0224	0.0030
	(-0.9862)	(-1.2897)	(0.2060)
Labour (humandays/ha)	0.2164*	0.0057	0.1950
	(2.0695)	(0.0318)	(1.5670)
Plant protection chemicals (g/ha)	-0.0043	0.4405*	0.3580*
	(-0.0307)	(3.1817)	(3.2020)
Irrigation (ha-cm)	0.0718	-0.4692	-0.1820
	(0.7202)	(-1.9252)	(-1.5170)
Nitrogen (kg/ha)	0.4667*	-0.1050	0.3030
	(2.6868)	(-0.4573)	(1.8290)
Phosphorus (kg/ha)	-0.3487	0.1987	0.3010*
	(-1.5887)	(1.1018)	(2.1160)
Potassium (kg/ha)	-0.1295	0.6506*	-0.0590
	(-1.9544)	(2.9334)	(-0.6720)
Intercept	8.1014**	4.2633	3.5070*
	(4.8621)	(1.4350)	(2.0230)
Intercept dummy	-	-	1.0000*
			(3.82)
Number of observations	35	35	70
R^2	0.6251	0.6784	0.7210
F-Value	5.4193**	6.8559**	17.1930**

Notes: ** significant at 1 per cent and * significant at 5 per cent levels
Figures within the parentheses denote t-values

Annexure II

Production function estimates for brinjal

Explanatory variables	Regression coefficients		
	Precision farming	Non-precision farming	Pooled with intercept dummy
Seed rate (g/ha)	0.1584	0.1130	0.0900
	(0.8203)	(0.4463)	(0.5620)
Manures (t/ha)	0.1106	-0.0212*	-0.0130
	(1.2860)	(-2.3748)	(-1.4920)
Labour (humandays/ha)	0.0087	0.3080*	0.1850*
	(0.0731)	(2.1705)	(2.2110)
Plant protection chemicals (g/ha)	0.1869	0.1274*	0.1180*
	(1.6079)	(2.6135)	(2.8150)
Irrigation (ha-cm)	0.0185	-0.1538*	-0.0560
	(0.2967)	(-2.6145)	(-1.2470)
Nitrogen (kg/ha)	0.3886*	0.7664	0.3980*
	(2.5815)	(0.8022)	(2.6590)
Phosphorus (kg/ha)	0.0614	0.1946	0.1480*
	(0.8415)	(0.5767)	(2.1810)
Potassium (kg/ha)	0.1103	-0.1771	0.0630
	(1.8550)	(-1.2353)	(1.1080)
Intercept	5.4508**	4.1318	5.4590**
	(4.7876)	(1.1728)	(6.3220)
Intercept dummy	-	-	0.4240*
			(2.6930)
Number of observations	35	35	70
R^2	0.7970	0.5594	0.7620
F-value	12.7602**	4.1260**	21.2800**

Notes: ** significant at 1 per cent and * significant at 5 per cent levels
Figures within the parentheses denote t-value

Annexure III

Geometric means of yield and inputs

	Tomato		Brinjal	
	Precision	Non precision	Precision	Non precision
Yield (kg/ha)	76882	40592	75921	57331
Seed rate (g/ha)	111	148	215	209
Manures (t/ha)	20	0.4	15	3.9
Labour (humandays/ha)	418	390	458	366
Plant protection chemicals (g/ha)	1981	2940	7254	2724
Irrigation (ha-cm)	88	392	84	407
Nitrogen (kg/ha)	206	270	261	275
Phosphorus (kg/ha)	40	190	26	175
Potassium (kg/ha)	30	172	70	231