Fertilizer Research 29: 267–274, 1991.

Changes in the nutrient status of soil caused by cropping and fertilization in a Typic Ustochrept

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Received 15 March 1990; accepted in revised form 16 May 1991

Key words: Targetted yield concept, Typic Ustochrept, buildup, depletion, balanced fertilization, soil fertility maintenance

Abstract

Field experiments were conducted during 1984–1986 on an alluvial (Typic Ustochrept) soil (pH 8.0, organic carbon 0.46%) at IARI farm, New Delhi to study the changes in available soil nutrients (N, P, K, Mn, Fe, Zn and Cu) at different production levels. Fertilizer was applied to wheat followed by maize, based on the 'Targetted yield concept', and mustard was grown after the sequence to estimate the residual effect of nutrients. Nutrient applications for the largest yield targets (6 t ha^{-1} of wheat followed by 4 or 5 t ha^{-1} of maize) resulted in a comparatively greater buildup of soil nutrients (N, P and K), the greatest yield of a succeeding mustard crop, and a better soil nutrient status than that at the start of the experiment, even after the mustard. When both crops were fertilized for the largest target yield with straight fertilizers (Urea, SSP and KCl), the additions of N, P and K and of micronutrient cations (Mn, Fe, Zn and Cu) maintained a favorable balance for major and trace nutrients and provided a sound basis for profitable crop production.

Introduction

Fertilizer strategies for sustainable agriculture and environmental protection are subjects of global concern today. Among agricultural inputs, fertilizer is the most important and costliest input in multiple cropping programs. A reasonable estimate would suggest that at least 50% of all grain production is directly attributable to applied fertilizer [9]. Proper fertilization strategies are crucial for the maintenance of soil fertility for sustained crop production. It is being increasingly realized that, when crops are grown in sequence, the fertilizer needs of the cropping sequence as a whole is more important than that of the individual crops. Factors to be considered include the preceding crop, its yield level and the residual effect of applied fertilizer. Thus the present investigations were undertaken on wheat and maize grown in sequence with fertilizer applications based on a 'Targetted yield concept'. The study was planned to evaluate the effectiveness of targetted yield equations for recommending the fertilizer application for the wheat-maize sequence, to monitor the changes in available soil nutrient (N, P and K, Mn, Fe, Zn and Cu), and for judging the maintenance/buildup of soil fertility.

The soil nutrient efficiency (CS) and fertilizer nutrient efficiency (CF) together with the nu-

* Part of the Ph.D. thesis of the senior author submitted to the Indian Agricultural Research Institute (IARI), New Delhi.

rient requirement (NR) are the essential parameters necessary for determining the amount of fertilizer required for specific yield targets based on this concept [10]. These parameters are calculated using the crop response data as follows:

$$\text{Nutrient requirement (NR)}: \frac{\text{Total uptake of the nutrient (kg ha}^{-1})}{\text{Yield of economic produce (t ha}^{-1})}$$

$$\text{Soil nutrient efficiency (CS)}: \frac{\text{Total uptake of the nutrient in control plot (kg ha}^{-1})}{\text{Soil test value of the nutrient in control plot (kg ha}^{-1})}$$

$$\text{Fertilizer nutrient efficiency (CF)}: \frac{\begin{bmatrix}\text{Total uptake of}\\ \text{nutrient in the}\\ \text{treated plot}\\ (\text{kg ha}^{-1})\end{bmatrix} - \begin{bmatrix}\text{Soil test value}\\ \text{of the nutrient}\\ \text{in treated plot}\\ (\text{kg ha}^{-1})\end{bmatrix}[\text{CS}]}{\text{Amount of the nutrient applied through fertilizer in treated plot (kg ha}^{-1})}$$

$$\text{Fertilizer dose (FD) (kg ha}^{-1}): \frac{\text{NR}}{\%\text{CF}} \times 100\text{xt} \begin{Bmatrix}\text{Yield target}\\ \text{t ha}^{-1}\end{Bmatrix} - \frac{\%\text{CS}}{\%\text{CF}} \times \begin{matrix}\text{Soil test value}\\ (\text{STV in kg ha}^{-1})\end{matrix}$$

$$: A_1 \text{ constant} \times t - A_2 \text{ constant} \times \text{STV}$$

(STCR) at IARI [2], New Delhi, as follows:

Wheat (HD2281)	Maize (Ganga-5)
$FN = 43.40\,t - 0.56\,SN$	$FN = 85.40\,t - 0.51\,SN$
$FP = 17.63\,t - 1.48\,SP$	$FP = 38.88\,t - 2.08\,SP$
$FK = 15.19\,t - 0.13\,SK$	$FK = 38.10\,t - 0.34\,SK$

FN, FP and FK stand for fertilizer N, P and K in kg ha^{-1} and SN, SP and SK stand for soil available N, P and K respectively in kg ha^{-1} from 0–15 cm soil depth, t denotes yield level to be targetted in t ha^{-1}.

Materials and methods

The field experiments were conducted during 1984–85 (post-rainy season) and 1985–86 (rainy and post-rainy seasons) on an alluvial (Typic Ustochrept) soil of IARI farm, New Delhi (latitude 28.4°N, longitude 77.1°). The soil of the experimental site was sandy loam, alkaline (pH 8.0), with an organic carbon content of 0.46%, available P content of 30 kg ha^{-1} and available K content of 210 kg ha^{-1} respectively (for methods used see later). The experimental designs followed were a completely randomised block for wheat (*Triticum aestivum* L. var. HD 2281) and a split plot for the following maize (*Zea mays* L. var. Ganga 5), with three replications.

The fertilization of wheat and maize was based on targetted yield equations obtained from soil test crop response correlation experiments

The six treatments for wheat were the prescribed N, P and K applications for targetted yields of 3, 4, 5, 6 t ha^{-1} and the general recommended dose (GR), i.e. N:P:K = 100:22:21 kg ha^{-1}, plus a control (no nutrients added). Each wheat plot was subdivided for five subplot treatments on maize, namely the N, P, and K dose for targetted yields of 3, 4, 5 t ha^{-1} and GR i.e. N:P:K = 120:26:33 kg ha^{-1} along with control. After the maize was harvested, mustard (*Brassica juncea* var. Pusa Bold) was grown to test for residual nutrients.

Wheat was planted in 1984–85 (December to April) in rows 22.5 cm apart and irrigated as and when needed using the basin system of irrigation. Half of the nitrogen, and all the P and K were applied before drilling and the remaining nitrogen was top dressed six weeks after sowing. After wheat, maize was grown in 1985 (June to October) in the rainy season with a spacing of 75 × 25 cm. A quarter of the nitrogen, and all of the P and K were band placed before sowing. Half of the nitrogen was top dressed at knee high stage and the remaining quarter at tasseling. The N, P and K were applied in the form of urea, single superphosphate and potassium chloride respectively. After maize, mustard was planted in 1985–86 (October–April) in rows 45 cm apart and basin irrigation was given as and when required. All the crops were harvested at maturity and threshed after thorough sun-drying to determine yields of grain and straw/stalk separately. The final weights were recorded after obtaining constant weights.

To monitor the changes in soil fertility more precisely, the initial main plots were divided into five subplots and surface soil samples (0–15 cm) were taken and analysed for available N by the alkaline permanganate method, available phosphorus by Olsen's method, available K using 1 $\underline{N}$ NH_4OAC, and available manganese, iron, zinc and copper by the DTPA method. The plant samples were analysed for N by a modified Kjeldahl method using an autoanalyzer. Solutions of plant material were prepared by wet oxidation [5]. The plant samples were analysed for P using the molybdovanado phosphate yellow method, K by flamephotometry, and manganese, iron, zinc and copper by atomic absorption spectrophotometry. The fertilizers (urea, SSP and KCl) were analysed, using the appropriate Association of Official Analytical Chemist methods [3] and the amount applied to wheat and maize were calculated. The various interactions of wheat treatments (W) with maize treatments (M) are represented by W × M and M × W, where W × M represents the various interactions of M within same wheat treatment (W) and M × W represents the various interactions of W within same maize treatment (M) and their other interactions as well. For comparison, only seven contrasting target treatment combinations have been selected here for presentation, including GR–GR and the control.

Results and discussions

Grain yield

The total grain yield of the wheat and maize crops and the deviations between targetted yields and those obtained are in Table 1. The maximum deviation was 8.7%, when targets for both crops were least (3 t ha^{-1} for both wheat and maize), while smaller deviations were observed in other target combinations. The maximum deviation between grain yields targetted and those obtained for wheat was 8.3% and for maize was 14.0% at their lowest yield target (3 t ha^{-1}). It seems that the targetted yield equations used in the experiment worked fairly well for the sequence as a whole and the individual crops. The R^2 values for multiple regressions of grain yield as the dependent variable on soil analyses and fertilizer applied (N, P and K) as independent variables were obtained for both crops individually and for the sequence as a whole. They were highly significant: 0.90** for wheat, 0.80** for maize and 0.82** for wheat-maize. This indicates that N, P and K fertilizers have been applied in balanced proportion with respect to soil and yield targets.

The maize treatments (M) and their interaction with wheat treatments (W) significantly affected the residual yield of mustard. The smallest yield (0.63 t ha^{-1}) was obtained on the control plot, followed by the general recommended dose (0.97 t ha^{-1}). Other target treatment combinations gave significantly larger yields than the control (Table 1). The maize crop in the general recommended dose (GR) treatment received considerably less N, P and K than the targetted treatments, which might have affected the residual yield of mustard. Other experimental results have shown that the yields targetted and those obtained of individual crops can be within a deviation of ±10% [14, 15].

Nutrient balance and available soil status of nitrogen, phosphorus and potassium

It is necessary to ensure a proper balance between the various nutrients present in the fertilizer and those already present in the soil. The GR for wheat and maize (WM) is the fertilizer

Table 1. Targetted and obtained grain yield of wheat (W) – maize (M) cropping sequence and residual yield of mustard (M_1)

Treat.	Yield targetted			Fertilizer applied (kg ha^{-1})						Yield obtained			Deviation	Residual
	t ha^{-1}			Wheat			Maize			t ha^{-1}				Mustard
	Wheat	Maize	Total	N	P	K	N	P	K	Wheat	Maize	Total	%	t ha^{-1}
W_0M_0	C	C	–	0	0	0	0	0	0	2.75	1.31	4.06	–	0.63
W_GM_G	GR	GR	–	100	22	21	120	26	33	4.16	3.16	7.32	–	0.97
W_1M_1	3	3	6	17	4	19	153	53	44	3.10	3.42	6.52	8.7	1.58
W_1M_2	3	4	7	15	3	23	238	92	90	3.25	3.82	7.07	1.0	1.53
W_2M_2	4	4	8	42	23	39	221	90	93	3.67	3.88	7.55	−5.6	1.54
W_4M_2	6	4	10	137	65	69	215	71	90	5.61	3.99	9.60	−4.0	1.34
W_4M_3	6	5	11	129	63	68	296	113	126	5.82	5.08	10.90	−0.9	1.61

	Grain yield							
	Maize				Mustard			
	W	M	W × M	M × W	W	M	W × M	M × W
SE±	0.11	0.10	0.25	0.25	0.15	0.05	0.13	0.19
CD at 5%	0.34	0.29	NS	NS	NS	0.15	0.37	0.54

GR – General recommended dose for Delhi region based on agronomic experiments
C – Control (no nutrients added); NS – Not significant

application arrived at without considering soil tests under irrigated conditions. It is based on earlier experiments where buildup and depletion of soil nutrient status were not considered. The fertilizer applied, based on the Targetted yield concept, aims for balanced nutrition with a necessary adjustment in fertilizer rate, according to soil buildup/depletion and yield targets. The N, P and K additions and removals were found to be largest under the largest targetted treatments (6 t ha^{-1} of wheat followed by 4 or 5 t ha^{-1} of maize). They decreased with the yield and soil test values, and the uptake was smallest on the control plots. The smallest target yield (3 t ha^{-1} of wheat and maize) was obtained using very little N, P and K fertilizer, and proved to be very profitable as more soil nutrients were utilized to achieve this yield. As the yield targets increase, less soil nutrients are utilized and more is taken up from fertilizer. The method thus adapts to the farmers' ability to invest in fertilizers. A positive nitrogen balance was observed in the wheat-maize sequence in most of the targetted treatments except the smallest target yield (3 t ha^{-1} of wheat and maize), where removal of N was slightly more than that added (Table 2). When nitrogenous fertilizers are applied in the field, some of the N is utilised by the crop but a considerable amount remains in the soil, depending on the soil type, the nature of the fertilizer and agroclimatic factors. Some of this N may be made available to succeeding crops if none is lost. It has been reported that an application of 40–80 kg N ha^{-1} increased the mineralisation of soil N and also increased the retention of fertilizer N in soil organic matter [1].

The phosphorus balance was also found positive in all the treatments except the control (Table 3); the smallest P balance was found under W_GM_G (general recommended dose) after wheat-maize. Some of the applied P was utilized by the crop, the remainder might have been chemically fixed, lost in runoff or immobilized by micro-organisms. The buildup or depletion of P status in the soil would indicate which were true. Both have been observed in other experiments [6, 7]. The positive balance here was partly caused by the moderate increase in the soil available P. A greater increase was observed under W_4M_2 and W_4M_3 (6 t ha^{-1} of wheat followed by 4 or 5 t ha^{-1} of maize).

A negative potassium balance was observed in the wheat-maize sequence in all the treatments (Table 4). This indicates that the K fertilizer applied was much less than that removed by the crops. However, available soil K increased in all treatments except the control after the wheat-maize sequence (Table 4); the largest increase

Table 2. Balance sheet of available soil nitrogen. (kg N ha^{-1})

Treat.	Target t ha^{-1} W	Target t ha^{-1} M	Wheat Initial Soil N	Wheat Addit.	Wheat Remov.	Wheat Post har. soil N	Wheat – Maize Total Addit.	Wheat – Maize Total Remov.	Wheat – Maize Balance	Wheat – Maize Post har. soil N	Wheat – Maize – Mustard Total Remov.	Wheat – Maize – Mustard Balance	Wheat – Maize – Mustard Post har. soil N
W_0M_0	C	C	213	0	64	186	0	116	−116	183	196	−196	177
W_GM_G	GR	GR	228	100	103	236	220	187	33	243	297	−77	237
W_1M_1	3	3	204	17	77	203	170	178	−8	235	324	−154	221
W_1M_2	3	4	206	15	79	204	253	192	61	237	325	−72	232
W_2M_2	4	4	238	42	87	236	263	208	55	258	343	−80	220
W_4M_2	6	4	223	137	151	249	351	248	103	270	380	−29	239
W_4M_3	6	5	236	129	136	256	425	274	151	278	436	−11	249

		Wheat – Maize W	Wheat – Maize M	Wheat – Maize W × M	Wheat – Maize M × W	Wheat – Maize – Mustard W	Wheat – Maize – Mustard M	Wheat – Maize – Mustard W × M	Wheat – Maize – Mustard M × W
Remov.	SE±	9	5	13	15	22	8	19	28
	CD at 5%	27	15	NS	NS	NS	22	NS	NS
Post har. soil N	SE±	7	2	4	8	7	3	7	10
	CD at 5%	22	5	11	22	NS	8	NS	NS

Treat = Treatment, Addit. = Addition, Remov. = Removal, NS = Not significant, Post har. = Post harvest.

was found under W_4M_3 (6 t ha^{-1} of wheat followed by 5 t ha^{-1} of maize). This is presumably because a dynamic equilibrium exists between solution, exchangeable and non exchangeable forms of K, and a considerable amount of K might have been mobilized from non exchangeable forms. Alternatively, K may have been taken up from subsurface layers in the soil. It has been reported that the application of K fertilizer resulted in the release of fixed K [4, 8].

Table 3. Balance sheet of available soil phosphorus, (kg P ha^{-1})

Treat.	Target t ha^{-1} W	Target t ha^{-1} M	Wheat Initial Soil P	Wheat Addit.	Wheat Remov.	Wheat Post har. soil P	Wheat – Maize Total Addit.	Wheat – Maize Total Remov.	Wheat – Maize Balance	Wheat – Maize Post har. soil P	Wheat – Maize – Mustard Total Remov.	Wheat – Maize – Mustard Balance	Wheat – Maize – Mustard Post har. Soil P
W_0M_0	C	C	35	0	17	28	0	27	−27	23	38	−38	19
W_GM_G	GR	GR	33	22	27	33	48	45	3	37	60	−12	27
W_1M_1	3	3	34	4	22	31	57	43	14	36	67	−10	26
W_1M_2	3	4	34	3	23	30	95	44	51	41	68	27	30
W_2M_2	4	4	32	23	25	31	113	49	64	42	74	39	29
W_4M_2	6	4	26	65	33	41	136	59	77	46	80	56	31
W_4M_3	6	5	29	63	32	39	176	66	110	55	90	86	32

		Wheat – Maize W	Wheat – Maize M	Wheat – Maize W × M	Wheat – Maize M × W	Wheat – Maize – Mustard W	Wheat – Maize – Mustard M	Wheat – Maize – Mustard W × M	Wheat – Maize – Mustard M × W
Remov.	SE±	2	2	5	5	3	2	4	4
	CD at 5%	8	5	NS	NS	8	4	NS	NS
Post harv. soil P	SE±	1	1	2	2	1	1	2	2
	CD at 5%	2	2	NS	NS	NS	2	NS	NS

Treat = Treatment, Addit. = Addition, Remov. = Removal, NS = Not significant, Post harv. soil P = Post harvest soil P 'able 4. Balance sheet of available soil potassium (kg K ha^{-1})

'reat.	Target t ha^{-1} W	M	Wheat Initial Soil K	Addit.	Remov.	Post har. soil K	Wheat – Maize Total Addit.	Total Remov.	Balance	Post har. soil K	Wheat – Maize – Mustard Total Remov.	Balance	Post har. soil K
V_0M_0	C	C	161	0	106	155	0	164	−164	155	221	−221	149
V_GM_G	GR	GR	184	21	167	190	54	237	−183	208	297	−243	202
V_1M_1	3	3	204	19	129	206	63	219	−156	215	305	−242	202
V_1M_2	3	4	179	23	125	182	113	216	−103	229	305	−192	207
V_2M_2	4	4	169	39	143	173	132	219	−87	228	299	−167	191
V_4M_2	6	4	168	69	162	185	159	251	−92	218	328	−169	195
V_4M_3	6	5	176	68	164	188	195	269	−74	240	351	−156	195

		Wheat – Maize W	M	W × M	M × W	Wheat – Maize – Mustard W	M	W × M	M × W
₹emov.	SE±	15	4	11	18	15	6	15	20
	CD at 5%	48	13	NS	NS	NS	17	NS	NS
'ost harv. ɔil K	SE±	8	1	2	9	5	3	7	8
	CD at 5%	NS	3	7	24	NS	8	NS	NS

'reat = Treatment, Addit. = Addition, Remov. = Removal, NS = Not significant, Post har. = Post harvest

'ost harvest available soil nutrients (N, P and K)

'he changes in soil nutrient status will differ rom soil to soil, crop to crop and even from eason to season. Keeping all the parameters at n optimum level, the changes in soil nutrient tatus can be predicted as a function of the initial oil test values, the applied fertilizer nutrients nd the actual yields of a crop in a given season, s outlined by Ramamoorthy et al. [11]:

hanges in soil fertility = f (observed yield, initial soil test and applied fertilizer nutrients)

'he regression model representing changes in ıvailable soil nitrogen is:

$$SN(PH) = A + B_1Y + B_2SN(I) + B_3FN$$

vhere PH is the post harvest soil test value and I is the initial soil test value of N; SN and FN represent soil and fertilizer nitrogen. The regression models for P and K can also be worked out in the same way. The prediction equation for a post harvest soil test value can be used to make a fertilizer recommendation for an entire cropping system. This is very useful because, under intensive agriculture, in most of the developing countries, the soils of the farmers' fields cannot be tested between each season and each constituent crop for practical reasons. The relationships between post harvest soil test values, fertilizer applied, initial soil test values and grain yield from the treated plots, for wheat (HD 2281) were:

	R^2	Multiple regression equation Wheat (HD-2281)
N	0.763**	$PHN(W) = 71.38 + 0.059\,Y^{**} + 0.54\,SN^{**} + 0.19\,FN^{**}$
P	0.530**	$PHP(W) = 16.45 - 0.0001\,Y + 0.34\,SP^{*} + 0.04\,FP^{**}$
K	0.917**	$PHK(W) = 15.58 + 0.001\,Y + 0.89\,SK^{**} + 0.17\,FK^{**}$

Here PHN(W), PHP(W), and PHK(W) stand for the post-harvest soil test values of N, P, and K (kg ha^{-1}); Y is the yield of crop (t ha^{-1}), SN, SP, and SK represent the initial soil test values of

N, P, and K (kg ha^{-1}), FN, FP, and FK represent the amount of fertilizer applied as N, P, and K (kg ha^{-1}) respectively. Similarly for the wheat-maize sequence:

R^2	Multiple regression equation: *Wheat (HD 2281)–Maize (Ganga-5)*
N 0.610**	PHN(W – M) = 126.89 + 0.015 WY + 0.17 WFN + + 0.32 WSN + 0.034 MY + 0.08 MFN
P 0.773**	PHP(W – M) = 13.93 + 0.013 WY + 0.01 WFP + 0.14 WSP + 0.017 MY + 0.03 MFP
K 0.604**	PHK(W – M) = 117.37 – 1.009 WY + 0.42 WFK + 0.51 WSK – 0.003 MY – 0.30 MFK

PHN(W – M), PHP(W – M) and PHK(W – M) are the post-harvest soil test values of N, P, and K (kg ha^{-1}) after the wheat-maize sequence, WY and MY denote the grain yield (t ha^{-1}) of wheat and maize; WSN, WSP and WSK, represent the initial soil test values of N, P and K (kg ha^{-1}) of wheat and WFN, WFP, and WFK represent the fertilizer N, P, and K (kg ha^{-1}) added to wheat, and MFN, MFP, and MFK are the amount of fertilizer N, P, and K (kg ha^{-1}) added to maize respectively.

Appreciably large R^2 values (significant at 1%) were obtained for these equations. This suggests that such regression equations can be used with confidence for the prediction of available N, P, and K after wheat and wheat-maize cropping sequences for making soil test based fertilizer recommendation for the succeeding crops. Appreciably large R^2 values were reported for phosphorus and potassium only under wheat and maize grown in Delhi soil [13].

Micronutrient cations (Mn, Fe, Zn and Cu)

Straight fertilizers (Urea, SSP and KCl) may contain small quantities of trace elements (Mn, Fe, Zn and Cu) depending upon the source of raw materials, equipment corrosion, catalyst and reagent materials added as fillers, coaters and conditioners. The fertilizers were analysed for their micronutrient contents. The largest contents of Mn (0.81 g kg^{-1}), Fe (4.81 g kg^{-1}), Zn (.072 g kg^{-1}) and Cu (0.062 g kg^{-1}) were found in SSP, whereas ∠1 g kg^{-1} of each was found in Urea and KCl (Table 5). Fertilizers originating from rock phosphates generally contain the largest amounts of trace elements [12].

When these straight fertilizers were applied, based on targetted yield equations there was an indirect addition of Mn, Fe, Zn and Cu to the soil. A positive balance was found for Mn and Fe (Table 6) after wheat-maize sequence for the greatest target yields (W_4M_2, W_4M_3). The positive balance of Mn and Fe was maintained in W_4M_3 even after the harvest of the residual crop of mustard.

Conclusion

It is possible to obtain targetted yields within ±10 percent deviation for a wheat-maize sequence. Balanced fertilizer application, using straight fertilizers and based on the 'Targetted yield concept' for production levels of 6 t ha^{-1} of wheat followed by 4 or 5 t ha^{-1} of maize in a wheat-maize sequence, was superior to all other treatment combinations and the general recom-

Table 5. Micronutrient cation analysis of fertilizers

Fertilizer	g kg^{-1} of fertilizer			
	Mn	Fe	Zn	Cu
Urea	nil	0.0153	0.001	0.001
Single super phosphate (SSP)	0.8075	4.8075	0.072	0.0615
Muriate of potash (KCl)	nil	0.109	0.003	0.0035

Table 6. Balance Sheet (Addit.–Remov.) of available soil manganese, iron, zinc and copper (g of Mn, Fe, Zn and Cu ha^{-1})

Treat.	Target		Wheat				Wheat – Maize				Wheat – Maize – Mustard			
	t ha^{-1} W	M	Mn	Fe	Zn	Cu	Mn	Fe	Zn	Cu	Mn	Fe	Zn	Cu
W_0M_0	C	C	−258	−1,238	−171	−58	−602	−5,442	−333	−112	−751	−6,592	−494	−154
W_GM_G	GR	GR	−246	−2,279	−223	−74	−333	−5,923	−448	−127	−531	−7,847	−624	−231
W_1M_1	3	3	−362	−2,352	−196	−76	−277	−6,676	−507	−124	−534	−8,321	−819	−204
W_1M_2	3	4	−320	1,578	−187	−63	−008	−2,118	−414	−086	−302	−3,486	−691	−156
W_2M_2	4	4	−123	0,001	−202	−51	424	−0,025	−451	−083	189	−1,274	−719	−156
W_4M_2	6	4	217	1,108	−218	−47	588	1,434	−384	−072	337	−0,283	−608	−153
W_4M_3	6	5	247	2,285	−219	−64	921	3,664	−434	−107	626	2,127	−684	−184

mended dose based on agronomic experiments. This approach maximised yield, improved soil fertility and maintained the nutrient balance for sustained crop production. However, values of the coefficients require further testing in an extended programme of field experiments on different soil types and agroclimatic regions.

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