THE GROWTH, NITROGEN UPTAKE AND YIELD OF SPRING-SOWN WHEAT ON LISMORE SILT LOAM

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ABSTRACT

The growth, nitrogen uptake and yield of 6 spring–sown wheats (cvs. Wakanui, Kopara, Pahau, Karamu, Oroua and Rongotea) were studied in the presence and absence of irrigation and N fertiliser.

Responses to irrigation were small, partly due to the high December rainfall (124mm), and partly to N deficiency, even when N fertiliser (54kg N/ha) had been applied. All cultivars initially took up N at similar rates. The nitrogen content of the crops levelled off after ear emergence, although mineralisation of soil organic N was continuing. The absence of any build–up of inorganic N in the soil suggested therefore that uptake was continuing, but was being cancelled out by losses from the crops. Atmospheric losses of volatile N compounds was considered to be the most likely explanation of these losses.

Pahau, Karamu, Oroua and Rongotea all yielded approximately 4000 kg/ha with 54kg N, compared to under 3000 kg/ha without N. Kopara and Wakanui produced similar total dry matter but much lower grain yields than the other cultivars. Baking scores of the 4 high yielding cultivars declined in the order Oroua > Rongotea > Pahau > Karamu, with flour protein levels showing a similar but much less marked trend.

INTRODUCTION

On the light soils of Canterbury, the main single factor limiting wheat yields is moisture. The other limitations inherent in a shallow soil are more difficult to specify. Because nitrogen is removed by the crop in greater quantities than any other nutrient, particularly in relation to available soil reserves, limitations in yield due to deficiency of this nutrient have received particular attention. Nevertheless, Drewitt and Rickard (1971,1973) found no responses to nitrogen in winter wheat crops which followed 3 or more years of pasture. Physical limitation of root growth may be the major reason for the relatively low yields obtained, compared with those on the deeper soils in Canterbury reported by Scott *et al* (1973) and Dougherty *et al* (1974).

Spring sown crops, however, require similar quantities of nitrogen to those sown in winter, but over a shorter time period. Frequently, much of the $NO_3 - N$ built up in these shallow soils in spring is leached out by rainfall, or by the first irrigation, before the young crop can utilise it. As a result, good responses to nitrogen may be obtained even where a crop follows pasture (Drewitt, 1979a).

Interpretation of the effect of nitrogen fertiliser on spring-sown wheat yields has been complicated by the interactions between irrigation and nitrogen status (Drewitt, 1979b). Because of this, an investigation of inorganic soil nitrogen levels, and nitrogen uptake by spring-sown Karamu, was commenced in 1976. This investigation was extended in 1978/1979 with the study of 6 wheat cultivars (*Triticum aestivum* L.) described in this paper. Kopara, a standard wheat most suited to autumn and winter sowing, has been widely sown in New Zealand since its introduction in the early 1970s. Karamu is a high yielding Mexican semi-dwarf derivative, first released in 1972. Despite reductions in payments because of variable baking quality, it continues to be widely sown as a spring wheat (and to a lesser extent as a winter wheat), particularly in Canterbury, Oroua, and the taller Rongotea, are being released in 1979 as replacements for Karamu, while Pahau is under pre-release testing. Wakanui has been withdrawn from trials.

This preliminary report does not attempt to describe all the results of this large trial, but rather seeks to feature and speculate on some of the more important and interesting aspects of growth and nitrogen uptake. Further results, including yield parameters, will be discussed in a future paper.

MATERIALS AND METHODS

The experiment was carried out on Lismore stony silt loam (300-450mm overlying gravels) as a first cereal crop following oats/ryegrass greenfeed, which had been sown after several years in pasture. Soil "Quick Test" analysis of the top 150mm at time of drilling (18 August) was pH 5.5, P 12, Ca 8, and K 8. Seed sowing rates (kg/ha) and weight (mg) for the 6 were Wananui 160,44; Kopara 170,48; Pahu 155,50; Karamu 140,44; Oroua 170,53. Superphosphate at 260kg/ha was applied with the seed, and N was applied to the main trial area at 54kg N/ha (as ammonium sulphate) at the second node stage (27 October). Small plots were left as nil N controls, while further plots received an additional 40 kg N/ha (i.e. 54 + 40 N) after ear emergence (17 December).

Irrigation was applied by the border–strip method when soil moisture in the top 150mm fell to 10% or 15%. The main experiment was a split plot design with main plots – irrigation (3 treatments) 70m x 9m; split plots – cultivars (6) 35m x 2.4m. There were 5 replicates, giving a total of 90 plots. Each of these plots contained nil N subplots and (54 + 40) N sub-plots.

Soil samples were taken at approximately weekly intervals from 20 September until harvest (7 February) from the 0–75mm and 75–150mm depths, and less frequently from the 150-300mm depth. These were analysed for NO_3 –N and NH_4–N by the hydrazine reduction/azo dye and phenol/hypochlorite automated colorimetric procedures respectively, after extraction of 4g soil with 20ml 1N KCL. All soil analyses reported are averages of at least 6 samples each containing 3 or more cores.

Plant samples were taken at two-weekly intervals from 15 November (early booting). Quadrats 300 x 300mm were taken from each replicate and bulked before separation into shallow roots, stems (including sheath), leaves (live and dead) and ears for dry matter and N determination. Total N was determined by the automated phenol/hypochlorite method following digestion with a $H_2SO_4/K_2SO_4/Se$ mix.

Crop yeilds at harvest were measured in $1m^2$ plots from each replicate for the main trial, which had received 54kg N/ha, and for the nil N sub plots. After removal of 50 heads from each plot for component analysis and chaff/grain separation, those remaining were thrashed for grain yield and N determination. Flour protein and baking score determinations were carried out by the Wheat Research Institute. The 54 + 40 N sub–plots were analysed for N uptake only.

RESULTS AND DISCUSSION

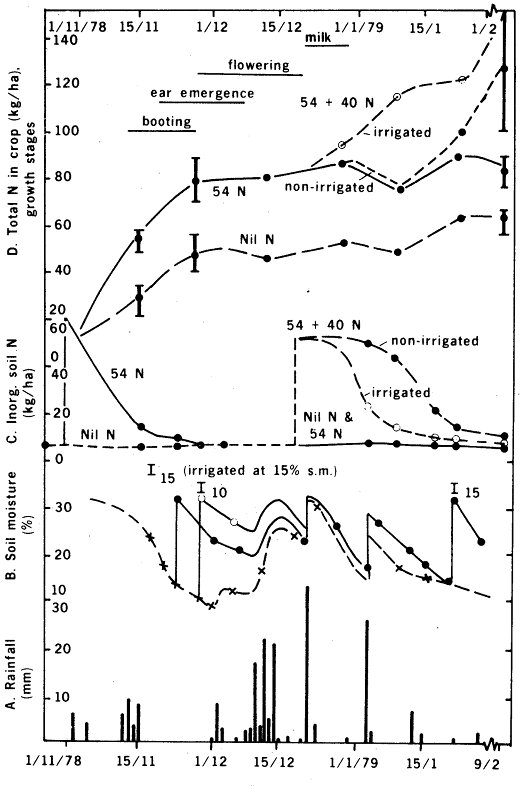
Rainfall and Soil Inorganic Nitrogen Status

Rainfall in the winter of 1978 was high (Table 1), and the leaching resulting from this prevented soil NO_3–N from building up to the usual level of 30-40kg/ha. At shoot emergence (20 September) the 0-300mm depth contained only 16 kg/ha NO_3–N and 7kg/ha NH_4–N. Soil depth varied from slightly less than 300 to 450mm over the area, and the 300–450mm depth contained an extra 10kg/ha NO_3–N and 1.5 kg/ha NH_4–N. Previous trials with spring–sown Karamu at Winchmore (B. F. Quin and E. G. Drewitt, unpublished data) had indicated that in the absence of significant leaching of NO_3–N, the N fertiliser requirement for maximum yield was approximately (80 –S) kg/ha, where S = kg/ha NO_3–N in the 0 – 300mm soil depth at shoot emergence. The 54kg N/ha applied was therefore expected to be close to that required. The fertiliser was not applied until 27 October, by which time the crop was at the second node stage, and soil inorganic N levels had been reduced to 7kg N/ha (Fig. 1C), of which only 2kg/ha was NO_3–N. Most of this reduction since 20 September was attributed to high September and October rainfall (Table 1). The applied N was rapidly depleted, at a rate of 15kg N/ha/week until 27 November, by which time soil N levels had been reduced to the same as those on the nil N plots (Figure 1C). During this period NO_3–N remained at very low levels (< 2kg N/ha), indicating that the rate of conversion of NH_4–N to NO_3–N by soil bacteria was limiting the rate of uptake. Because of this, and because the soil moisture did not exceed field capacity during this period (Fig 1B.), crop uptake rather than leaching was considered to be responsible for almost all the decline in soil N levels.

TABLE 1: Monthly rainfall, Winchmore (mm)

	1978/79		1950-1976	
June	94		51	
July	132		63	
August	74		67	
Winter		300		181
September	159		42	
October	91		61	
November	36		65	
Spring		286		168
December	124		69	
January	39		64	
February	42		57	
Summer		205		190
9 months	791		539	

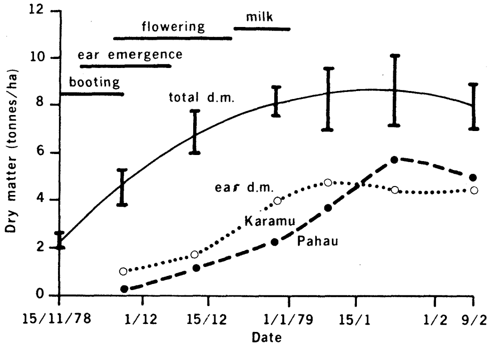
Figure 1: A. Rainfall (mm), B. Soil moisture (0-10 cm), C. Inorganic soil N (NH_4 - N + NO_3 - N, 0-300 mm), D. Total N in crop (above ground), growth stages. Bars show range for 6 cultivars.



Crop Growth

Karamu and Oroua reached the boot stage by 13 November, Rongotea shortly afterwards, then, in order, Kopara, Pahau and finally Wakanui on 27 November, by which time Karamu had completed ear emergence. Despite the spread in stages of development over the 6 cultivars, all varieties increased in total dry matter at similar rates, for a given irrigation treatment and nitrogen supply, up until the milk stage (Figure 2). The contribution to total growth made by the ear reflected the state of development (Figure 2.).

Figure 2: Total crop and ear dry matter, 54 kg N and irrigation at 15% soil moisture. Bars show range for six cultivars.



There was no consistent response to the irrigation at 10% on 28 November, probably because subsequent rainfall prevented the soil moisture from dropping below 10% on the non- irrigated treatment (Figure 1B). The irrigation at 15% on 23 November had however produced and immediate response on the main trial (54N), suggesting that the 10% and non–irrigated treatments suffered moisture stress during the booting/ ear emergence period of 23 – 28 November.

Mineralisation of Soil N and Crop Uptake

During the period of 27 September to 27 November, the nil N sub–plots gained an average of 7kg N/ha/week for the 6 cultivars, compared to 12kg N/ha week where 54N had been applied. The range in N content for the 6 cultivars, shown by the bars, was not very large (Figure 1D.). As differences between irrigation treatments were minimal, the treatments were averaged.

The gain of 7kg N/ha/week on the nil sub-plots occurred while soil inorganic N levels were maintained at extremely low levels (Figure 1C); this gain is therefore an estimation of the rate of mineralisation of organic N. Laboratory incubation of field–moist soils indicated a mineralisation rate of 7–10 kg N/ha/week from the 0–300mm depth, with little extra contribution from deeper depths.

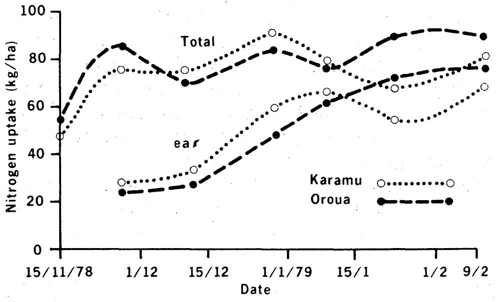
Assuming that applied N does not greatly reduce the rate of mineralisation (this is supported by laboratory data), then the wheat topdressed with 54kg N/ha would have been taking N up at the rate of 7 (from mineralisation) + 15 (rate of removal of fertiliser N) = 22Kg/ha/week. The actual increase in N content of only 12kg/ha/week over the period 27 October to 27 November suggests that losses from the plant of approximately 10kg/ha/week were occuring.

Following ear emergence, little further gain in average crop N content occured (figure 1D), although variation between cultivars and between sampling dates became considerable. Mineralisation was however continuing at the same rate (as demonstrated by further incubations), and the absence of any build–up of inorganic N in the soil demonstrated that uptake was continuing. Losses from the crops must therefore have been continuing at equivalent rates. Leaf fall could not have explained the lack of increase in crop N, as total leaf N content did not exceed 20kg/ha for any cultivar after ear emergence, and in any case senescent leaves invariably contained extremely low levels of N. Similarly, storage in the roots was discounted because the N content of the roots in the top 150mm never exceeded 10kg/ha, and actually declined after ear emergence until harvest, in agreement with the results of the detailed study of spring wheats roots carried out by Campbell *et al* (1977a). Further, a sudden increase in excretion of N compounds from the roots after ear emergence is very unlikely, as translocation studies show that movement of N in the plant is very largely towards the developing ear (McNeal *et al.,* 1968). Finally, volatilisation of fertiliser N from the soil has been shown to be negligible under these circumstances (B. F. Quin, unpublished results.). The most likely explanation of the lack of increase in crop N is that volatile N compounds (such as ammonia and amides) are lost to the atmosphere from the foliage during transpiration. Gaseous loss of volatile N compounds has been proposed as the "missing link" in N budgets for various crops, including corn (Porter *et al,* 1972; Terman and Allan, 1974), rhodegrass (Martin and Ross, 1968), and winter wheat (Daigger *et al.,*1976). The latter authors postulated that only gaseous losses (presumed to be NH_3), could explain the huge fluctuations in the N content of winter wheat during growth and particularly maturation. Considerable temporary or permanent declines in the total N content of wheat from ear emergence onwards have been frequently reported (Boatwright and Haas, 1961; Storrier, 1965; Allison, 1973; Campbell *et al.* 1977b); these losses were not satisfactorily explained.

Recently, attempts have been made to measure gaseous N losses from crops. Stutte and Weiland (1978) found that N losses from various crop species increased markedly with temperature, and estimated a growing season loss of 45kg N/ha for soybean. N was thought to be lost mainly in oxidised and reduced forms (Stutte *et al.,* 1979). Denmead *et al.,* (1978) measured sustained losses of NH_3 to the atmosphere above a corn crop, greatest losses coinciding with maximum transpiration rates.

The data presented in Figure 1D indicate that losses from wheat increase following ear emergence. This is compatible with the higher concentrations of volatile N compounds present in the plant during translocation of hydrolysed protein from stems, leaves and chaff to the developing grain. Furthermore, the concentration of N into the uppermost portions of the wheat plant after ear emergence allows little opportunity for the volatile N lost to the atmosphere to be reabsorbed by the plant, as happens in pastures (Denmead *et al.,* 1974, 1976). Different cultivars showed different patterns of N accumulation and losses. For example, Karamu irrigated at 15% showed a more rapid translocation of

Figure 3: Nitrogen content of total crop and ears. 54 kg N and irrigation at 15% s.m.



N to the ear than Oroua (Figure 3), but this is followed by a substantial drop in both ear and total N.

Late Application of N

Because the N content of the crop did not increase after ear emergence (Figure 1D), a further application of 40kg N/ha (also as ammonium sulphate) was applied to small plots on 19 December, at the end of the flowering phase. The irrigated plots quickly showed an increase in N content for all cultivars (Figure 1D), whereas increased uptake on the non–irrigated plots did not occur until after heavy rain on 3 January (Figure 1A). The dry conditions prevailing in the top few mm of the non-irrigated plots may have been sufficient to delay nitrification of the ammonium sulphate. The increased N content was manifested mainly in the stems and ears, with little increase occurring in the N content of the leaves of any cultivars. This suggests that this late–applied fertiliser N was translocated directly to the ear.

TABLE 2: Total above ground N yield, mean and range for 6 cultivars (kg/ha)

	Non-irrigated		Irrigated at 15% s.m.	
	mean	range	mean	range
nil N	60.5	58 - 63	64.5	62 - 67
54 N	84.8	77 - 89	83.8	77 - 89
54 + 40 N	135	110 - 160	150	120 - 160

Nitrogen Yields at Harvest

All cultivars yielded similar quantities of N under a given N regime, and irrigation treatments had little effect (Table 2). Inclusion of root N content in the totals would not alter this picture as, two weeks before harvest, root N content in the top 150mm was less than 5kg/ha in all cultivars in all treatments. The results demonstrate that, on average, less than 25kg N/ha of the 54kg applied to the main trial could be accounted for in the plant at harvest. The N content of the plots which received an additional 40kg, however, increased by as much if not more than the amount applied: late applied N may actually reduce atmospheric losses by slowing the rate of breakdown of leaf protein.

TABLE 3: Grain yields kg/ha (corrected to 12% moisture), and grain indices.

	Non-irrigated		Irrigated at 15% s.m.	
	nil N	54 N	nil N	54 N
Wakanui	2250 bA .38	2220 bC .31	2610 bcA .35	2570 bB .30
Kopara	2470 abA .40	2750 bBc .36	2300 cA .37	2670 bB .31
Pahau	2580 abA .46	3340 aAB .45	2930 aA .46	3900 aA .43
Karamu	2360 abA .46	3820 aA .51	2820 abA .46	4040 aA .50
Oroua	2530 abA .43	3780 aA .45	2690 abA .44	4090 aA .42
Rongotea	2830 aA .42	3650 aA .42	2720 abcA .42	4180 aA .41
C V (%)	13.9	13.1	13.9	13.1

Duncan's lettering refers to yield figures within a column (P $<$ .05 and $<$.01 for lower and uppercase letters respectively).

Grain Yields

Karamu, Pahau, Oroua and Rongotea all had similar yields (Table 3), and the semi–dwarf Karamu had the highest grain index (fraction of total above–ground dry matter in the grain). Moreover, Karamu's grain index was higher where 54kg N had been applied than on the nil sub-plots, on both the non–irrigated and irrigated plots.

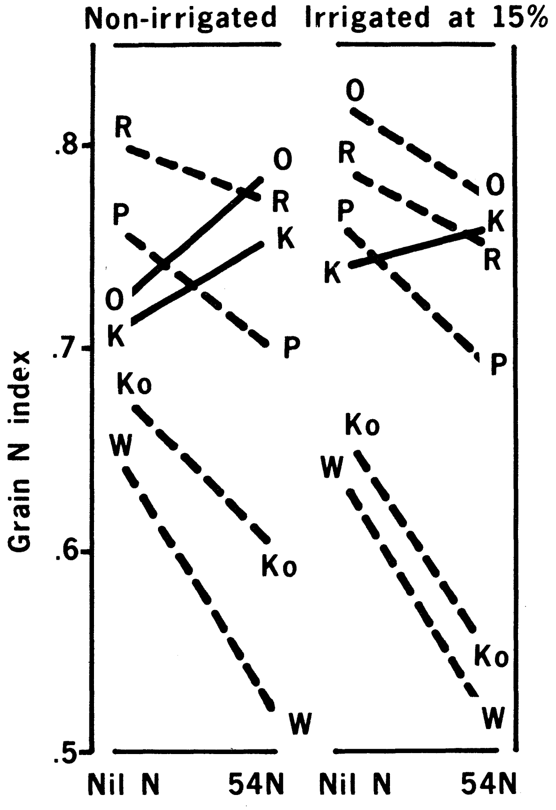
The grain index of all other varieties decreased with applied N on the 15% treatment, although Oroua and Rongotea showed little change on the non–irrigated plots. Oroua had the highest ear numbers/m^2 of the 6 cultivars on all irrigation treatments; Pahau invariably had the lowest (Drewitt and Quin, in preparation).

The grain yield of the 2 cultivars that are not generally regarded as being suitable for the spring sowing in Canterbury, namely Kopara and Wakanui, did not respond to N or irrigation (Table 3), even though total dry matter was increased.

Grain N Index

In the absence of applied N, Karamu had a lower grain N index (fraction of above–ground crop N in grain) than the other similar yielding cultivars (Figure 4), indicating less efficient translocation of leaf and stem protein, especially as Karamu had the lowest leaf and stem dry matter. This relative inefficiency of translocation is also demonstrated by the differences in stem N concentrations at harvest (Table 4). However, where N was applied, the grain N index for Karamu improved (Figure 4), whereas all the others (with the exception of non irrigated Oroua), decreased. This suggests that Karamu has a relatively high basal chaff, leaf and stem N content which cannot be translocated to the grain (17kg/ha in this trial compared to only 12kg/ha for Oroua and Rongotea), but that any increase over this basal value

Figure 4: Grain N indices (Ko, Kopara; K, Karamu; O, Oroua; P, Pahau; R, Rongotea; W, Wakanui).



resulting from the application of N fertiliser is translocated more efficiently in Karamu than in the other cultivars, probably because vegetative growth is not stimulated to the same extent. This may in part explain the relatively high dependence of Karamu baking quality on N supply.

Flour Protein and Baking Quality

Although flour protein levels were slightly lower in Karamu than in Oroua and Rongotea (Table 5), they were higher than those in Pahau, and in any case the differences in baking quality were out of all proportion to the differences in protein levels. Baking quality is obviously more dependent on the quality than on the concentration of protein. Moreover, although responses of protein level to applied N and irrigation can be explained in relation to yield responses, there was no clear–cut trend for improving baking quality with increasing protein levels for a given cultivar. Oroua gave the highest (although variable) scores, while Karamu failed to reach the desired minimum in any treatment.

TABLE 4: Stem N concentrations at harvest (%)

	Non-irrigated		Irrigated at 15% s.m.	
	Nil N	54 N	Nil N	54 N
Karamu	.58 aA	.44 aAB	.38 abcAB	.39 bcB
Pahau	.34 bBC	.41 abAB	.32 bcdAB	.33 bcdBC
Oroua	.35 bBC	.28 cC	.28 cdB	.32 cdBC
Rongotea	.24 cC	.32 bcBC	.26 dB	.26 dC
C V (%)	22.5	17.8	22.5	17.8

Duncans' lettering refers to figures in columns (P<0.05 and <0.01 for lower and upper case letters respectively).

TABLE 5: Flour protein (%) and baking score.

	Non irrigated				Irrigated at 15% s.m.			
	Nil N		54 N		Nil N		54 N	
	fp	bs	fp	bs	fp	bs	fp	bs
Wakanui	8.9	15	9.4	12	9.2	15	8.5	13
Kopara	10.0	17	10.2	11	10.1	17	9.5	12
Pahau	9.0	21	9.2	12	9.2	18	83.	11
Karamu	9.5	<5	9.5	<5	9.7	<5	8.6	<5
Oroua	9.9	27	10.3	27	10.6	25	9.5	20
Rongotea	9.7	19	10.3	17	10.2	13	8.9	15

fp = flour protein; bs = baking score (Mechanical Dough Development test).

GENERAL CONCLUSIONS

Crop N content increased at similar rates for the 6 cultivars until ear emergence, then levelled off, despite a continuation of mineralisation of soil organic N. It was concluded that considerable losses (perhaps 10kg/ha/week) of N from wheat crops were occurring, particulary after ear emergence and where N fertiliser had been applied. The most likely explanation was considered to be gaseous losses of volatile N compounds from the foliage to the atmosphere, these losses being most pronounced during hydrolysis and retranslocation of leaf and stem protein.

These losses led to a low final recovery of fertiliser N applied at the second node stage. In contrast, N applied after ear emergence was quantitatively recovered, suggesting that late – applied N is, to a large extent, translocated directly to the ear before assimilation into protein, thereby avoiding losses which occur during hydrolysis and retranslocation of protein. Nevertheless, early–applied N is not necessarily less efficiently utilized than late– applied N. Previous trials at Winchmore have shown that, provided that mineralisation rate is sufficient (as generally it is) to ensure that crop N content continues to rise after ear emergence, despite any losses that are taking place, then fertiliser N can be quantitatively recovered regardless of the time of application. This suggests that there is a maximum rate of N loss from the crop, perhaps 15kg/ha/week.

The semi–dwarf Karamu has a relatively high basal level of non translocatable leaf, stem and chaff protein at low fertility levels. In conditions of higher N–fertility however, translocation of almost all the plant N above this basal level occurs, which although leading to greater losses than that which occurs with other cultivars, also leads to very high grain N indices. Unfortunately however, the baking quality of Karamu is not closely related to flour protein concentration. The similar yielding Pahau, Oroua, and Rongotea cultivars were all shown to be suitable replacements for Karamu.

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