ROTHAMSTED RESEARCH

Report for 1974 - Part 1

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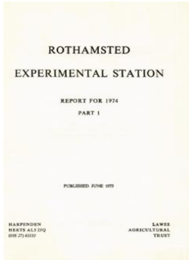
ROTHAMSTED
EXPERIMENTAL STATION
REPORT FOR 1974
PART 1

Physics Department

J. A. Currie

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Introduction

In origin, and to some extent by tradition, the department was concerned with the physics of the soil. Today, in no small part due to the leadership of H. L. Penman, our interests cover the whole plant environment. We have still tended, however, to report our work either as Soil Physics, or Micrometeorology, for though we are well aware of the importance of the vital internal link between root and leaf, we have done little work on its physics. This division has been accentuated by the stage of development of each subject. Micrometeorology is universal, young, and dependent largely on only weather and crop. Most of its aspects can be considered in terms of the interaction of a single gaseous continuum on the discrete solid plant phase. But because the continuum is a gas, the system is subject to rapid changes which are not only hard to follow, but greatly increase the number of measurements that must be taken and the problems of subsequent interpretation. Further difficulties arise because we are frequently unable to specify clearly and accurately the boundaries between plant and air, and between crop and atmosphere. Partly because of these uncertainties and partly because the system neither starts nor stops at such boundaries, we have extended our interests more recently through the stomatal cavity into the plant.

By contrast, soil physics is an older subject. Many of the physical generalities of the soil are known and today we are more often concerned with the parochial problems, trying to explain for example why one soil gives greater yields than another when physically they seem the same, or conversely why two obviously different soils should yield equally. Soil unlike the air above it is a three phase system with solids, water and air in varying proportions. It is in this system that the roots and organisms must live and through it that they must move. This, however, is a gross oversimplification of the situation; we recognise this and then conveniently forget it. Herein, perhaps, lies the reason why the soil physicist, quite capable of making measurements that ought to be relevant, has as yet failed to characterise adequately the soil as a root environment. The particulate nature of soil, the particle properties, its history and its management all go to make what we call structure. While structure determines the probable distribution of air and water within the soil pore space (and hence the transport 'constants' for these commodities) it also determines whether the plant roots are in air, in water, or more intimately

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in contact with nutrients adsorbed on solid surfaces. The roots need all three. In the past we have been much pre-occupied with their *availability* expressing this as an appropriate quantity or as a potential: there is a limit to the progress that can be made this way. Today we are more aware of the importance of *accessibility*. This suggests that there are preferred paths along which these commodities must move or be sought. When we can satisfactorily identify these paths, we can try to measure more relevant transport constants and then with the appropriate potentials, solve a few more of the transport equations that are an essential part of our work above and below ground. Soil structure is, moreover, unstable and so that we can continue to be aware of the changes that this can bring to the various transport systems, we retain an active interest in structural stability.

The Departmental work

The mobile shelter. This is, perhaps, the most exciting innovation in the work of the department. Increasingly we are using irrigation not so much as an end in itself but as an additional variable in our environmental studies. With a mobile cover we have now the facility to keep water off and thus extend the water regime to include controlled drought. But this project has been fraught with difficulties that have meant experimental work scheduled for this year had to be postponed. The civil engineering work on foundations, put out to contract in 1973 and scheduled to be completed that year, had to be demolished because of discrepancies in level and alignment, and was re-built during the winter. The resulting quagmire on the experimental area has been successfully reclaimed—another tribute to the kindly nature of the Rothamsted soil. The year has not been completely lost, however, as much of the auxilliary equipment for measurement and control, has been brought to a greater state of readiness than otherwise.

There are two covers, arched in section, each 10·5 m wide, 20 m long and 3·5 m high. Though essentially open ended structures, reinforced polythene curtains can be lowered at each end to crop height. Each cover runs on rails 52 m long and eventually will be mechanised to move into position over the crop when it rains. Two experiments are planned for alternate years using the experimental area in one year as the parking area for the cover in the other. At one end, concrete tracks 27 m long have been provided to support tractor and implements in a tillage experiment. At the other there will be an irrigation experiment with a wider range of treatments than has been possible hitherto in the field. This will allow a detailed study of the physics of water movement through stressed plants and of the influence of water stress on chemical composition and subsequent yield of the crop.

The intensity of experimental effort that will be required on both experiments, and the bringing together of equipment on one site for both soil and atmospheric measurements provide unique stimuli for future work on the whole physical environment of the crop in a single experiment. (Brown, Legg and W. Day)

The stability of soil structure. As the first part of a programme to study the nature of the bonds between soil particles it is necessary to develop a method to test their strength more precisely. Ultrasonic irradiation seemed to be a suitable tool for this purpose. It is becoming an accepted method for dispersing soil suspensions before particle size analysis (see paper 6) but in this role quantitative information on the effective dispersive power applied is lacking. The energy available for dispersion from an ultrasonic probe generator was measured as the difference between the heat output in water (total energy) and the somewhat smaller heat output in an equivalent volume of soil suspension at the same probe current with the probe immersed to the same depth. The increase in soil dispersion with increasing dispersive energy was then observed for several soils. Dispersion was

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assessed either as the amount of <20 μm particles in a pipette sample, or the amount of <2 μm particles obtained using a Joyce Loebl disc centrifuge and derived turbidity—particle size curve. Both showed a sharp increase with initial increase in energy but then became almost constant over a region where dispersion was probably complete but where some particle disintegration continued to occur. The energy level corresponding to the edge of this plateau, i.e. complete dispersion with minimum disintegration, is a measure of the binding energy or stability of the soil matrix at this semi-micro level. Defining a *specific stability index*, σ (J g^{-1}) as the energy required to disperse completely one gram of soil, the indices for several soils may be compared (Table 1).

TABLE 1

Specific stability index for soil structure

Soil	Organic carbon %	Fraction <20 μm %	Index σ (J g^{-1})
Rothamsted			
Highfield permanent pasture (surface)	2·6	46	30
Highfield permanent pasture (10–15 cm)	2·3	51	20
Barnfield headland	0·5	52	6
Little Knott (0–20 cm)	1·5	49	9
Little Knott (40–65 cm)	—	59	2
Woburn			
Road Piece (0–7 cm)	1·4	22	6
Road Piece (25–48 cm)	0·3	14	<1

These figures are consistent with known behaviour of the soils in the field. (North)

Simultaneous movement of water and salt: hydrodynamic dispersion. When water or salts move independently through soil, it is sufficient to measure a hydraulic conductivity for one and effective diffusion coefficients for the other. When as is more usual they are both moving the liquid moves as before, but progress of the salt is determined by hydrodynamic dispersion in which the salt spreads relative to the mean velocity of water flow with an accelerated diffusion coefficient K, called the dispersion coefficient. Examples where hydrodynamic dispersion is important are the leaching of salts from soils, movement of nutrients towards the root, and evaporation from saline soils. For a recent review of some aspects of hydrodynamic dispersion see Rose (*Journal of Soil Science* (1973) **24**, 284–295).

In the mathematics of this process, the concentration of the salt C and the distance along the soil column X are normalised to be in the range 0–1 and the time T is normalised as the number of pore volumes of liquid that have passed through the soil. At any time five pieces of information are important:

(i) the salt profile $C(X, T)$

(ii) the salt concentration in the effluent $C_e = C(1, T)$

(iii) the distribution of residence times of the salt within the soil

(iv) the amount of salt in the soil $= \int_0^1 C \, dX$

(v) the amount of salt leached from the soil $= \int_0^T C_e \, dT$.

The graph of effluent concentration against time $C_e(T)$ is referred to as the breakthrough curve and, in the laboratory, is easily measured. The distribution of residence times is given by $\partial C/\partial T$, the slope of the breakthrough curve.

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The mathematics of a number of problems have been examined and the computer used to find the above five quantities.

In one problem hydrodynamic dispersion follows a steep change in concentration at the soil surface as for example when one solution displaces another through a soil column, or when a uniformly saline soil is leached. Here the five quantities depend only on one dimensionless parameter B (= UL/K) where U is the flow velocity in the soil and L the length of the column or profile. B may have values between the limits zero (diffusion but no flow) and infinity (infinitely fast flow with little dispersion—piston flow). As B increases both the breakthrough curve and the salt profile become steeper. Ten sets of boundary conditions were considered.

A more complicated problem occurs when a finite band of solute e.g. pesticide or saline crust on topsoil, is washed into the soil, for dispersion then occurs from both the leading and trailing edges of the band. Another dimensionless parameter S is needed, the ratio of the initial volume of the dissolved band to the pore volume of the soil, and though the mathematics are more bulky, the behaviour of the salt depends only on B and S. The best analytical solution for different purposes can be specified from the nine sets of boundary conditions considered.

Three other problems, more relevant to the laboratory than the field were tackled similarly, the dispersion of a triangular pulse of solute, the dispersion of a solute whose influent concentration varies sinusoidally, and dispersion at an air-water boundary where evaporation occurs. (Rose and Hughes)

All mathematical analyses carried out are general and require no knowledge of K. A leaching experiment has been started on the undisturbed soil of the Rothamsted drain gauges from which it is hoped to get an estimate of K in the field. (Rose and A. Day)

The leaching of a thin band of salt by a single application of irrigation water was studied in a sand, a loam, and a clay. The water infiltrated rapidly producing an almost symmetric salt distribution. Subsequently, as the wetting front moved down and the water drained from the initially wet surface, salt built up just behind the wetting front and diffused upwards towards the soil surface producing a pear-shaped salt profile characteristic of the process. (Rose and Maurya)

Soil respiration. In previous years many of the soil respirometers carried a summer crop (dwarf beans) which caused an increase in soil respiration corresponding to the vigour of the crop. In late October 1973 three tanks were planted with wallflowers (*Cheiranthus cheiri*) to measure the effect of a winter hardy 'crop' on soil respiration. Between October and May respiration trebled and, apart from perturbations caused by unseasonal weather, increased steadily. By contrast the uncropped tanks followed the usual pattern reaching their annual minimum during February. After flowering the plants deteriorated rapidly shedding most of their leaves and by June respiration had fallen to the basal 'soil only' level.

One respirometer had remained sealed for over four years, had carried no crop, received no additional water and lost only little by the limited evaporation possible in a closed circulation system. An analysis of the weekly carbon dioxide output over this period eliminated the effect of differences between annual temperatures and indicated that the organic matter contributing most to soil respiration had a 'half life' of 3·14 years. Results for 1974, the fifth year, suggest the half life of the remaining organic matter is greater.

The effects of diurnal changes in soil temperature with time and depth on the apparent respiration rate in a soil profile have been calculated for several sets of boundary conditions. Changes in respiration with a sinusoidally varying temperature (period 24 h) have been measured in the laboratory; oxygen uptake varies cyclicly but not quite

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sinusoidally confirming field experience; carbon dioxide evolution varies similarly, but because of two major artefacts in the system for measuring carbon dioxide in the field respirometers this had not hitherto been demonstrated. The respiratory quotient over that part of each cycle for which measurements of both oxygen and carbon dioxide were taken was $1{\cdot}00 \pm 0{\cdot}03$. (Currie and Pritchard)

Soil water. Three new neutron moisture meters have been constructed to replace older units (Long & French, *Journal of Soil Science* (1967) **18**, 149–166). Part of the circuitry has been re-designed to take advantage of recent component miniaturisation and integrated circuit techniques. The volume of the unit has been halved and the weight with batteries is now only 4 kg. (Long)

Water extraction has been measured under wheat, kale, potatoes and short grass, using the new meters. (French and Croft)

Attempts to measure the spatial distribution of wheat roots (var Kolibri) by following the pattern of water withdrawal in pots using resistance blocks were more successful when the soil was dried to the range $-0{\cdot}5$ to $-1{\cdot}0$ bar than at $-0{\cdot}05$ to $-0{\cdot}2$ bar. (Maurya and Rose)

Irrigation: Rothamsted. Wheat was sown in both autumn (1973) and spring, at normal seed rate in 7-in. drills or at quarter rate in 14-in. drills, with nitrogen at 45 or 90 kg N ha^{-1}, and with full irrigation or none. The dry spring necessitated 75 mm water in four applications between early May and mid-June with a further 25 mm in the third week of July. Autumn sowings produced 6·0–7·4 t ha^{-1} grain compared with only 2·6–5·1 t ha^{-1} from the spring wheat, but yields were little affected by the other treatments: irrigation caused no change in the yield of grain + straw but depressed grain from 7·0 to 6·3 t ha^{-1}; quarter seed rate gave less grain + straw but the same grain as the normal rate; both rates of nitrogen produced the same yields. The other treatments produced more variation within the spring sowing: the lighter seed rate decreased the grain + straw from 8·2 to 5·3 t ha^{-1}; irrigation increased grain + straw from 4·7 to 5·9 t ha^{-1} at the lighter seed rate, and from 7·5 to 8·9 t ha^{-1} at the normal seed rate, but decreased grain from 3·1 to 2·9 and from 5·1 to 4·8 t ha^{-1} respectively at the light and normal seed rates. Growth analyses throughout the season support these results. The slower growth rate of the spring crop during May probably caused the decreased yields. Irrigation improved the rate of growth of the spring crop during May and June, but the cause of the depressed grain yield is a mystery.

Kale grown on the remaining blocks required only 25 mm irrigation given in late July. This decreased yields from 82 to 76 t ha^{-1} (fresh weight). (French, Croft, Susan Thurgood and Legg)

Irrigation: Woburn. Our attempts to advise the Nematology department on irrigating the potatoes in their eelworm experiment were frustrated by the theft of irrigation equipment during the previous winter. When the first 12·5 mm were applied in late June, much of the benefit to be expected in a dry spring had been lost. Nevertheless, irrigation increased yield from 28·8 to 31·5 t ha^{-1} on the plots with small nematode populations but decreased yield from 10·9 to 7·5 t ha^{-1} where populations were large. (Legg, as adviser)

Plant water potential. Pressure bomb measurements were made on wheat and potato plants. Both the ear and flag leaf of wheat had potentials greater than -1 bar at sunrise on 7 June decreasing to about -6 bar in the ear and -11 bar in the leaf at midday and rising again to -4 and -7 bar respectively by 1900 h. On 7 July these potentials reached minima of -13 and -16 bar. On both days stomatal resistance was greater on the

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unirrigated plots but no sudden increase with decreasing water potential was observed. By contrast minimum potentials in potato leaves on 7 June reached only −7 to −8 bars. (Whitehead and W. Day)

Two types of thermocouple psychrometers, one for leaf and one for soil water potential have been tested. Both are of the double thermocouple type using Peltier cooling in one junction to give a 'wet bulb' temperature. At high water potentials these require at least 3 h to equilibrate with the sample. (W. Day)

Carbon dioxide uptake

Mesophyl resistance. Measurements of the rate of carbon dioxide assimilation in potato leaves in response to light intensity and carbon dioxide concentration were reported last year. The resistance to CO_2 transfer between leaf surface and the chloroplasts was obtained by plotting photosynthesis against CO_2 concentration and measuring the slope of the line. By subtracting the stomatal resistance, the mesophyl resistance is obtained. Mesophyl resistance generally increased from 4·0 to 6·0 s cm^{-1} in a 12-week period starting on 20 June, and tended to increase in both magnitude and variability with the the age of the leaf. (Parkinson and Caroline Philpot)

Photosynthetic efficiency. The light response curves for the same leaves gave a photosynthetic efficiency of 12·6 μg CO_2 J^{-1} for light of wavelength 400–700 nm (equivalent to 16% efficiency).

Field enclosures. Two enclosures were available, but of necessity shared one set of control and measuring equipment so limiting the output from each. The first was placed over an area of potato crop (Pentland Crown) and from measurements on irrigated and unirrigated plots, comparative estimates of carbon dioxide uptake were made. Water was applied in early June (40 mm in two applications) and at the end of July (25 mm, one application). Until late July carbon dioxide uptake was greater on the irrigated plots and on both increased with leaf area. After July there was little difference between plots and uptake fell. The trends were confirmed by growth analysis. (Leach, French and Whitehead)

Carbon dioxide uptake increased with the input of solar radiation to reach a maximum of 4·9 g m^{-2} h^{-1} (ground area) at between 350 and 400 W m^{-2} (wavelengths 400–3000 nm). At this point light saturation seemed to occur. Few measurements were made at >600 W m^{-2} because of a continual lack of bright sunshine.

Uptake also increased with air temperature from 2·7 to 4·0 g CO_2 m^{-2} h^{-1} between 16 and 24°C, corresponding to a Q_{10} of 1·58. Above 24°C uptake declined rapidly and inexplicably to 2·1 g CO_2 m^{-2} h^{-1} at just over 25°C (all measurements in the light intensity range 310–340 W m^{-2}). (Leach)

The second enclosure was placed over one of the soil respirometers providing an opportunity to study gaseous exchange above and below ground simultaneously and separately on the same plants. Three respirometers were involved in this study, one carrying the enclosure, one with identical bean plants (*Phaseolus coccineus* cv Hammond's Dwarf Scarlet) for growth analysis and one with soil only to provide an estimate of the 'soil' component of respiration. Measurements were made over successive hourly periods on several days unfortunately too often in overcast weather. (Sale with Leach and Currie)

Single leaf measurements. Carbon dioxide uptake has also been measured on individual leaves in the potato crop. Compressed air from a cylinder was passed for 2 min at 500 ml min^{-1} through a small cup clipped onto the leaf. The outflow, collected in polypropylene/aluminium foil bags was then analysed in an Infra Red Gas Analyser for

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carbon dioxide. Uptake reached 3·5 g CO_2 m^{-2} h^{-1} at noon on bright days and in well watered plants values of 2·0 g CO_2 m^{-2} h^{-1} were maintained as long as light intensity was high. On 29 July with soil water deficits of 9 and 60 mm respectively on irrigated and unirrigated plots assimilation rates were 3·0 and 1·8 g CO_2 m^{-2} h^{-1} the difference being attributed to stomatal resistances of 1·2 and 5·0 s cm^{-1}. (Whitehead)

Oxygen concentration on plant growth. It had been reported (Parkinson *et al.*, *Journal of Experimental Botany* (1974), **25**, 132–146) that plant growth was more rapid at 5% than 21% oxygen and this was ascribed to an increase in net photosynthesis. Leaf size was, however, also affected and it was felt that a change in leaf structure and hence in mesophyl resistance might instead have been responsible. In attempts to verify this possibility tomato plants failed to produce new leaves and tobacco became chlorotic at 5% oxygen. Further efforts are being made using beans (*Vicia faba*). (Caroline Philpot)

Micrometeorology. The decision to fallow the macro-plots to control persistent weeds has meant that we have had much needed time to look at the mass of results accumulated in previous years, to service and modify existing equipment, and to build new sensors.

Analysis of results. The development of computer programs for analysing past (and future) records has been continued. Three main aspects have been pursued simultaneously and hopefully will be brought together soon to good effect. The program for the energy balance has already run successfully on results for several complete days and with modified output will now be used on a whole year. In the program for calculating evaporation and heat flux by the aerodynamic method the first task has been to fit a satisfactory curve to the wind profile. A log-linear relationship is adequate (Wedderburn, Statistics Department) but as this currently has three parameters often fitting only five experimental points a simplification is sought. This program is being run on the results of one year to see if one of the parameters can be eliminated. (Legg)

It is often difficult to begin to interpret very large numbers of results and some time has been spent exploring the use of the incremental plotter to display them. The graphs produced are certainly attractive and probably useful. (Legg)

A program for the de Wit model for light penetration within a crop has been run successfully this year. This and the Monteith model will be used with radiation measurements and results from leaf chambers to give estimates of field photosynthesis for comparison with measured CO_2 fluxes. (Legg and Parkinson)

Measurements on turbulence within wheat (Legg, Ph.D. Thesis, 1971) have been re-examined and by discarding all those for periods in which the temperature gradient changed sign, a mean diffusion coefficient has been calculated for one height interval (0·3–0·8 m) in a crop 1·25 m tall. This diffusion coefficient depends only on wind speed and a non-dimensional stability parameter analogous to the Richardson number. (Legg and Long)

Movement and deposition of spores. A computer program for calculating gaseous diffusion in cereal crops has been modified to simulate spore dispersal and deposition. First results show that a comparison of computed and measured spore concentrations downwind from the point of origin are in reasonable agreement. (Legg, Evans with Powell and Bainbridge, Plant Pathology)

Instrumentation. A further eight Sheppard cup anemometers have been modified for use with a Stogate data logger. The modifications also improve resolution but necessitate a

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complete recalibration. Two new interface units have been constructed to match the anemometers to the data logger.

The rotating wind tunnel for providing vector air flow has been completed and the three-cup horizontal airflow anemometers and the miniature four-blade vertical airflow units have been calibrated. The vertical airflow anemometers have the ideal cosine response in both up draft and down draft. The horizontal airflow anemometers have similar characteristics to the larger Sheppard type but have much smaller momentum and a lower starting speed of 3·5 cm s^{-1} (c.f. 15 cm s^{-1}).

Additional soil heat flux plates have been constructed to an improved design. The thermopiles are wound on Jena glass microscope slides and sandwiched between aluminium plates. They have a thermal conductivity of 10 mW cm^{-1} $°C^{-1}$ and a sensitivity of 15 μV W^{-2} m^2. (Long)

Staff and visiting workers

H. L. Penman retired at the end of March. He came to Rothamsted in 1937 from the Shirley Institute for Cotton Research, Manchester, and in 1954, when R. K. Schofield moved to the Chemistry Department, he succeeded him as Head of the Physics Department. Penman is perhaps best known for his work on natural evaporation, for subsequent work on irrigation at Woburn and Rothamsted, and for his wide interest in hydrology. During his leadership, Penman at all times encouraged interest in the Physics of the whole plant environment, not just of the soil where the department had its origin. At the time this report is written, no successor has been appointed. Meanwhile J. A. Currie is acting Head.

W. Day joined the staff in January to work on water relationships within the plant. N. C. Evans, C. W. Hughes, Caroline Philpot and Susan Thurgood were here as sandwich course students. Dr. P. J. M. Sale returned to Griffith, Australia in August, and Dr P. R. Maurya to India at the end of his Commonwealth Scholarship. Mr. T. G. Takla, Planning Manager, the Behara Land Co., Alexandria, spent six weeks in the department.

B. J. Legg attended the 1974 International Seminar on Heat and Mass Transfer in the Environment of Vegetation, at Dubrovnik, in August where, with Professor J. L. Monteith, he gave an invited paper. D. A. Rose attended the 10th Congress of the International Society of Soil Science held, in August, in Moscow.

Publications

General Papers

1 Legg, B. J. (1973) Weather 1972 *Transactions of the Hertfordshire Natural History Society* **27**, 239.

2 Prew, R. D. & Legg, B. J. (1974) An unusual freezing phenomenon. *Weather* **29**, 217 & 219.

Research Papers

3 Currie, J. A. (1974) Soil respiration. *Technical Bulletin. Ministry of Agriculture, Fisheries and Food* **29**, 459–466.

4 Legg, B. J. & Long, I. F. (1973) Logging equipment to collect micrometeorological information. *National Institute of Agricultural Engineering Report* No. 12.

5 North, P. F. & (Champion, J. V.) (1974) Hydrodynamic degradation of DNA. *Journal de Chimie Physique* **71**, 1282–1284.

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6 PRITCHARD, D. T. (1974) A method for soil particle-size analysis using ultrasonic disaggregation. *Journal of Soil Science* **25**, 34–40.

7 SZEICZ, G. (1974) Solar radiation for plant growth. *Journal of Applied Ecology* **11**, 617–636.

8 SZEICZ, G. (1974) Solar radiation in crop canopies. *Journal of Applied Ecology* **11**, 1117–1156.

9 SZEICZ, G. (VAN BAVEL, C. H. M. & TAKAMI, S.) (1973) Stomatal factor in the water use and dry matter production by sorghum. *Agricultural Meteorology* **12**, 361–389.

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