# TECHNOLOGY IN THE GRECO-ROMAN WORLD: A GENERAL REPORT *

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*Oegstgeest*

It seems a generally accepted truth that the ancient Greeks and Romans did not excel in mechanical technology or applied science. Ancient machines, that is devices powered by so-called prime-movers [1] other than muscular power of man and animals, were few; those which did exist were either toys,[2] developed by that rare figure, the engineer-scientist, or, to the extent that they managed to break through the ivory-tower of his 'laboratory', devices which do not seem ever to have been used on any significant scale. Those devices which were developed and which were powered by man or animals (e.g. hoisting-apparatus and instruments for raising water) were not many either (compared with what the ancient world produced in other branches) and their use was late and by no means universal. The principles of the gear and the screw had been discovered but their application was far from common.

* Somewhat elaborated text of a paper read at the Economic History Congress in Bloomington, U.S.A. in 1968. Since there does not seem to be much hope that the Congress Acta will be published before long, the text is presented here. I have not managed to take advantage of all the relevant literature which has appeared since 1968.

[1] On 'prime movers' see R. J. Forbes, *Studies in Ancient Technology*, vol. II, 1955, 78 ff.

[2] Cf. e.g. Archytas' mechanical dove and the Alexandrian automata. According to Pappus the art of those who contrive marvellous devices is a section of mechanics in which the mechanicians employ air pressure, ropes and cables to simulate the motions of living things (see M. R. Cohen—I. E. Drabkin, *A Source Book in Greek science*, 1948, 184). To this category belonged the altars described by Hero on which two figures poured a libation, apparently by their own efforts (the principle used being the expansion of (and pressure exerted by) hot air) and the automatic opening of temple doors when a fire was lit on the altar. (Here, too, the principle was the same as that of the 'automatic' libation, combined with a complicated system of ropes and pulleys). Vitruvius lumpts these kinds of 'inventions' together under the heading of 'useless objects that flattered the senses by amusing the eye and ear' (X. 7. 4; cf. also § 5 "quae sunt ad deliciarum voluntatem" (that serve for our amusement)).

I am not sure that the ancients would have been happy with the above statement on the general mediocrity of their world in technical matters. To be really acceptable both to them and to ourselves our generalization, like so many others, should be properly qualified.

First, there is a good deal of evidence to show that some Greeks were by no means hostile to *technē*. A comprehensive study of the word *technē* and its derivates is still non-existent, as far as I know.[3] Such a study should take into consideration both the litterary and the epigraphical sources in order to present a sociologically differentiated picture. For the moment I can do no more than cite a few pieces of evidence, chosen at random. I begin with Anaxagoras' well-known dictum that "man is the wisest of living creatures because he has hands" (διὰ τὸ χεῖρας ἔχειν φρονιμώτατον εἶναι).[4] All creatures have their share in mind (νοῦς). It is the physical structure that determines the quality of the mind. Baldry [5] rightly notes that we have here "the notion of man as a tool-using animal whose superior achievement . . consists in what we now call 'technical development' ". Unfortunately we do not know how A. elaborated his view.[6] For Aeschylus Prometheus' fire is the teacher of all τέχνη (διδάσκαλος τέχνης πάσης).[7]

The gradual invention and development of the *technai* are indispensable for the progress of human civilization. Both the science of numbers and mining belong to these *technai*. 'Pure' science and

[3] The study by M. Ismardi Perente, *Techne: Momenti del pensiero greco da Platona ad Epicuro*, Florence 1966, was inaccessible to me. For the early Greek period see R. Schaerer, 'Επιστήμη *et* Τέχνη: *Étude sur les notions de connaissance et d'art d'Homère à Platon*, 1930.

[4] Diels-Kranz, *Fragm. der Vorsokratiker*[5], II, Anaxagoras B 102. Aristotle emphatically rejected Anaxagoras' view. In his view, of course, reason and wisdom come first; the hands are an *organon* that obeys the commands of λόγος; their position is secondary. Cf. also F. Lämmli, *Homo Faber: Triumph, Schuld, Verhängnis?*, Basel 1968, 32 and 35 on Anaxagoras' easy combination of *sophia* and *technē*.

[5] Baldry, *The Unity of Mankind in Greek Thought*, 1965, 29. On the importance of the hand in Greek thinking see also W. Spoerri, *Späthellenistische Berichte über Welt, Kultur und Götter*, Basel 1959, 148-152.

[6] In the light of Anaximander's and Thales' technical achievements (sundial; olive-press) it is by no means inconceivable that Anaxagoras also "used his hands" for other purposes than the making of a globe.

[7] Aeschylus, *Prometheus* 506; cf. J. P. Vernant, *Prométhée et la fonction technique* in *Mythe et Pensée chez les Grecs: Études de psychologie historique*, 1965, 185 ff., esp. 193; F. Lämmli, *op. cit.*, 99, note 147.

crafts are equally important.[8] The 4th century tragedian Antiphon exclaims proudly and self-confidently, though unfortunately in an unknown context: "By our *technē* we are able to subdue those forces (or creatures) which by nature are superior to us" (τέχνῃ κρατοῦμεν ὧν φύσει νικώμεθα). Our hands enable us to overcome the physical (natural) inferiority we have over against animals.[9] Through our hands we mould and shape our mind, so to speak. The results of this process of moulding and shaping are the products of *technē*.[10] A similar emphasis on the important function of the hands and the invention of *technai* is to be found in a passage from Diodorus (I, 8) [11] where Prometheus is replaced by χρεία as the teacher of all things, among which the *technai* are to be counted, that can promote community life. Man is a gifted student because he possesses hands, which help him in everything, reason and sagacity. Once again the hands enable a man to materialize his intelligence and thereby to create civilized community-life. Seneca's 90th letter testifies to Poseidonius' positive view of the *technai*, at least in their initial stages: the philosophers are credited with the rise of technique.[12] An equally positive view of the rise and products of

[8] Cf. Vernant, *loc. cit.*

[9] See F. Heinimann, *Eine vorplatonische Theorie der* Τέχνη, Mus. Helv. 18, 1961, 105 ff., esp. 118, note 60; F. Lämmli, *op. cit.*, 146, note 347.

[10] It is perhaps not entirely fortuitous that Antiphon the tragedian was employed at the court of Dionysius, the 4th century B.C. *tyrant* of Syracuse. Elsewhere (Acta Historiae Neerlandica II, 1967, 6 ff.; cf. also Mnemosyne 1963, 443) I have stressed Dionysius' strong interest in *technē* and *technitai* (Diodorus XIV. 42.1). He engaged at high salaries a great many experts from all parts of the world to ensure the manufacture of weapons. In the process several war-engines and ballistic devices were invented. The restless organiser and innovator Dionysius must have appreciated the spirit embodied in Antiphon's slogan. However, for all his technological interest Dionysius did not direct the skill of his technitai to agriculture, food-processing or manufacture. A century later the Ptolemies (above all Ctesibius) supported the research of the so-called Alexandrian engineers in military technology. The social function of their technological devices was again equally non-existent; see M. I. Finley, *Technical Innovation and Economic Progress in the Ancient World*, Econ. Hist. Rev. XVIII, 1965, 29 ff., esp. 37; see now also Lämmli, *op. cit.*, 71 (for a judicious discussion of Statius' panegyric on Domitian as roadbuilder, who subdues nature for the benefit of the people) and 115, note 226 (tyrants-technai).

[11] See W. Spoerri, *op. cit.*, (see note 5), 148 ff.

[12] *Ep.* 90.7-13; 20-25; S. Blankert, *Seneca over natuur en Posidonius als zijn bron*, Diss. Utrecht 1940.

the '*artes* = *technai*' is taken by Vitruvius who sees in the fertile interplay of hand and thought the main cause of the inventions made by man in the course of his history: ". . from the construction of buildings they progressed by degrees to other crafts and disciplines and they led the way from a savage to a peaceful civilisation".[13] In his introduction to the final book of his work Vitruvius shows a positive attitude towards machines and instruments: "our fathers developed the comforts of life by their inventions".[14]

On the other end of the scale we have the commoners who in their epitaphs on dedications pride themselves on their *technē*. They range from the Paphlagonian slave Atotas who worked in the Athenian silvermines and proudly advertised his *technē* in his epitaph,[15] to the Lycian stone-cutter Paion who pretends to have been "λαινουργῶν τέχνηι κάλλιστος" (supreme in the stone-cutters art).[16] An Athenian potter exclaims that it is proper for the wise to be a skilfull, clever craftsman and that he who has *technē* has a much better life.[17] Bolkestein and de Robertis have collected much evidence to show that in the greco-roman world craftsmen often show considerable self-esteem.[18] Some argue that deep in their heart

[13] Vitruvius, *De architectura* II. 1.6.

[14] Vitruvius, *De architectura* X. 1.4.

[15] Τέχνηι δ' οὔτις ἔριζε: IG II² 10051; S. Lauffer, *Die Bergwerksklaven von Laureion*, vol. II, p. 199 f. ("An Kunst nahm es keiner mit mir auf").

[16] G. E. Bean-Harrison, JRS 57, 1967, 43, n. 8.

[17] A. E. Raubitschek, *Dedications from the Athenian Acropolis*, 1949, n. 224 (ca. 500 B.C.).

[18] H. Bolkestein, *Wohltätigkeit und Armenpflege im vorchristlichen Altertum*, Utrecht 1939, 326 ff.; F. M. de Robertis, *Lavore e lavoratori nel mondo romano*, 21 ff.; E. M. Staerman, *Die Krise der Sklavenhalterordnung im Westen des römischen Reiches*, Berlin 1964, 114 ff. Unfortunately Staerman seems to assume that glorification of labour and technical skill begins to emerge not until the late first and second century A.D., that is, in a period during which (according to St.) the slave-owners try to offset the increasing lack of interest of the slaves in their affairs by more humanitarian legislation and a rather paternalistic ideology. The slave-owners do not succeed in so reconciling the slaves with their increased exploitation. In order to reverse the downward trend of productivity the slaves are transformed into *coloni* and thereby rediscover the joy of working. Throughout her book Staerman fails to distinguish between a structural and chronological approach. In stead of assigning the evidence for a positive attitude towards labour and technical skill to a narrowly limited period, and interpreting this attitude as a reaction upon the slaveholder's ideology and as a result of the transition from slavery to colonate, it would be well to realize that inscriptions in which commoners

these craftsmen may well have admired the upperclass ideal of independence and leisure.[19] However, for the time being they made at least a virtue out of necessity. Their self-esteem shows that large groups in ancient society would have been seriously insulted by the common view about the mediocrity of the ancients in the field of technique. And quite apart from the views of ancient *technitai* themselves, on the basis of modern scholarship we may say with some confidence that antiquity produced many examples of very sophisticated technique. The crucial point, of course, is that in the above-mentioned inscriptions *technē* primarily refers to the activity of the skilled craftsmen to the merits of whom our musea and excavations largely testify and (with the partial exception of Vitruvius) not to mechanical technology.[20]

The nine volumes of R. J. Forbes' *Studies in Ancient Technology* [21] abundantly show what ancient craftsmen and artisans achieved in their often primitive workshops. The aesthetic quality of their products is, in M. I. Finley's words, "psychological, not technological".[22] The artisans were proud of their skill; they were not driven by a constant desire to improve their technique systematically and scientifically. They were proud of their tools and their ability to handle them but they were not bent on either improving

express their philergia *do not belong to one period*. A comprehensive account of all the evidence will, I am sure, show that pride in one's work and skill is as old as the work and the skill itself. See provisionally J. Robert, REG, 1967, 282; L. Robert, *Stèles Funéraires de Byzance*, 160-162; Hellenica XIII, 38; SEG XVIII, 456.

[19] P. A. Brunt, *Aspects of the social Thought of Dio Chrysostom and of the Stoics*, Proc. Cambr. Phil. Ass. 1973 (nr 199), 9 ff., esp. 14.

[20] Vitruvius (partly) and Poseidonius are concerned with building, mining, weaving, baking and farming. Poseidonius ascribes the invention of certain tools to "*viri sapientes*". However, he presumably showed no sympathy to certain advanced contemporary techniques like glassblowing and hypocaustbuilding. Where exactly P. drew the borderline between 'philosophical inventions' and vulgar arts I am not sure, but perhaps it was between *ta anagkaia* (the necessary items) and *tryphē* (luxury; cf. Plato, *Politeia* 369a-373d; *Nomoi* 677a and Lämmli, *op. cit.*, 52). How exactly Poseidonius defined these two conceptions we do not know but it is perhaps not unreasonable to assume that the *vitrearius* belonged to the realm of *tryphē*; he was not a true *vir sapiens* but rather a citizen of Plato's *tryphōsa polis*.

[21] Leiden 1955-1964; see also F. Kiechle, *Sklavenarbeit und technischer Fortschritt im römischen Reich* (Wiesbaden 1969), for a good survey of advanced techniques, often related to the production of luxury items.

[22] *art. cit.*, (see note 10), 30.

them themselves or on adopting improvements excogigated by others. In the course of time small improvements, taught by *the experience* of generations of ancestors, were made to existing equipment/tools; but there were "few signs of mechanical improvements in the routine process of agriculture".[23] And those innovations which are reported to have been made were used in limited areas only.[24] A good example is provided by the ancient methods of threshing. The oldest method was to have the grain trodden out by animals; another possibility was the use of an animal-driven threshing sledge, "an obvious improvement on the ancient method of treading out the grain with animals".[25] This sledge was considerably improved by adding wheels; the so-called *plostellum punicum* was a small wagon with wheels and a driver mounted upon it. Columella (2.20.4) who in other respects was by no means uninterested in efficiency, writes: "if you have a few teams (of horses) you may hitch them to a threshing sledge—"; the implication is that if a farmer has enough cattle or horses, the "obvious improvement" was not practised.[26] As to the "plostellum", it was probably rarely used outside Spain, where it had been developed by the Carthagenians.[27] One can imagine an ancient peasant priding himself in his epitaph on his zeal, his φιλεργία and showing

[23] K. D. White, *Agricultural Implements of the Roman World*, Cambridge 1967, 13-14; see also G. E. Fussell-A. Kenny, *L'équipement d'une ferme romaine*, Annales 1966, 306 ff., esp. 323.

[24] Ch. Parain, *Le problème de la diffusion réelle des progrès techniques dans l'agriculture romaine*, in Sozialökonomische Verhältnisse im alten Orient und im klassischen Altertum, ed. R. Günther-G. Schrot, Berlin 1961, 228 ff. works back from a study of agricultural implements in the pre-industrial period to antiquity. He not unreasonably assumes a continuity in the use of tools in agriculture. From this approach the striking fact emerges that certain improved or newly developed tools (*e.g.* the ventilabrum, threshing sledge; oilpresses, plough, flail, scythe), described by ancient authors, were only used in limited areas. North-Italy and Gaul take pride of place. Central and Southern-Italy were (and still are) backward technically.

[25] White, *op. cit.*, 155.

[26] Cf. in the same sense H. Dohr, *Die italischen Gutshofe nach den Schriften Catos und Varros*, Köln 1965, 127/8.

[27] White, *op. cit.*, 156: "Although its rotary action will have made it more efficient than the *tribulum*, the absence of any reference in Columella's lengthy treatment of threshing-methods (2.20.3-5) would imply that it had not found favour in Italy"; on the *plostellum poenicum* see also Dohr, *op. cit.*, 128.

on his tomb-relief his agricultural implements;[28] but one should not jump to the conclusion that the man was therefore interested in technology.

Striking parallels to the threshing implements are available in what happened to oil-presses. From A. G. Drachman's study it appears that mill-stones and their cores were improved by craftsmen in the course of time so that the efficiency of the presses increased.[29] On the other hand a completely new type of oil-press described by Pliny and Heron of Alexandria, the so-called screw-press has by no means expelled the traditional presses. The screw-press is admirably discussed and reconstructed by Drachmann in his recent work on mechanical technology in the ancient world:[30] "they are easy to work—there is no need in them for a beam nor for a very heavy stone nor for string ropes: they are free from all that and press with a strong pressure and the juices come out altogether".[31] Hero compares the screwpress, in which the screw has to be turned now and then to renew the pressure, with the lever-press. In Italy archeologists seem to have dug up lever-presses only, though the new and more efficient type was known there as witnessed by a south-Italian fresco. In North-Africa only a few screw-presses have been found; the majority of the African oil- and wine presses belongs to the old type.[32]

There is nothing to show that the Sophists and all those who had a positive view of human hands and *technai* and who therefore could tempt us into believing that they were Denis de Rougemont's

[28] The number of epitaphs for peasants is small; a recent survey in Jeanne Robert, REG 1967, 282 ff. Pliny the Elder's anecdote on the freedman G. Furius Chresimus (*N.H.*, 18.41-43) shows the successfull farmer's pride on his implements.

[29] A. G. Drachmann, *Ancient Oil Mills and Presses*, Copenhagen 1932; see also M. I. Finley, *art. cit.*, 29.

[30] A. G. Drachmann, *The Mechanical Technology of Greek and Roman Antiquity*, Copenhagen 1963, 126 ff.

[31] Hero, *Mechanica* III, 19; see also Pliny the Elder, *N.H.*, 18.317.

[32] Cf. F. Kiechle, *Das Problem der Stagnation des technischen Fortschritts in der römischen Kaiserzeit*, Geschichte in Wissenschaft und Unterricht XVI, 1965, 89 ff.; id., *op. cit.* (cf. note 21), 32 ff.; Ch. Parain, *art. cit.*, 232/3. Significantly enough, as M. I. Finley acutely pointed out (*art. cit.*, 33; contra L. Edelstein, Journ. Hist. Id. XIII, 1952, 573 ff., esp. 583), Pliny knew no inventor's name, though in general the ancients had a passion for recording names of inventors (πρῶτοι εὑρεταί); cf. also Lämmli, *op. cit.*, 146, note 352.

precursors ("penser avec les mains"), had a real interest in mechanical technology and in the development of labour-saving and labour-replacing devices. In a series of very subtle articles the French scholar J. P. Vernant once more has made the point that, if, e.g., Protagoras has a positive interpretation of τέχνη, we should beware of assigning to 5th century words what in our world is interpreted as a proper technical mentality. The Sophists' views on τέχνη should be interpreted within the context of their own "Weltanschauung": "Il n'y a pas une pensée technique, immuable . . qui s'orienterait comme la nôtre, en fonction d'un dynamisme spontané, vers le progrès. Chaque système technique a sa pensée propre".[33] Protagoras' positive view of *technē* [34] primarily stems from his belief in the "république des artisans" as opposed to what has been called the "république des paysans".[35] The 'artisan' deserves his place in Athenian democracy. Both Plato and Protagoras agree that in the system of exchange of products and services, without which a city cannot exist, the artisans are indispensable.[36] We all know that Plato (and for that matter Aristotle too) nevertheless gave the artisans an inferior position in their politeia. Protagoras was more consistent. He provided the ideology for the actual position of the artisans in Athenian democracy. However, it should be borne in mind that the artisans do not participate in civic life as such but as human beings who have their share in *aidōs* and *dikē*.[37]

Protagoras compares the world of man with his manifold technical δυνάμεις (potentialities) with the realm of the animals, each species

[33] J. P. Vernant, *Remarques sur les formes et les limites de la pensée technique chez les Grecs*, in *Mythe et Pensée chez les Grecs*, 1965, 227 ff., esp. 228 and 233.

[34] *Protagoras* 324 c-d; Vernant, *op. cit.*, 209.

[35] I borrow this expression from R. Goossens' paper *La république des paysans*, RIDA IV, 1950 (Mélanges F. de Visscher, tome III), 551-577; cf. Cl. Mossé, *La fin de la démocratie athénienne*, Paris 1962, 369 and P. Vidal-Naquet, *La tradition de l'hoplite athénien*, in *Problèmes de la guerre en Grèce ancienne* (sous la direction de J.-P. Vernant), Paris-La Haye 1968, 161 ff., esp. 170.

[36] Vernant, *op. cit.*, 209-210, 214-215. In Revue Historique 212, 1954, 209 ff. Ed. Will presents a searching analysis of Plato's and Aristotle's views on the function of the exchange of goods and services in a community. They admit that because of the inequality of, e.g., a shoe and a house a generally accepted standard of value is indispensable. In principle χρεία (need) is this standard; for without χρεία there would be no exchange. In actual life money is that standard: it is the ὑπάλλαγμα τῆς χρείας.

[37] *Protagoras* 320 e, ff.

of which is endowed with a specific *dynamis*. This means that Protagoras' thoughts on technique are embedded in a rather static over-all picture of *nature*. By exercising his métier the artisan (the *technitēs*) obeys to the principle which governs *nature*.[38] It was natural that a shoemaker satisfied the need (*chreia*) of a carpenter and vice versa. Society was a carefully balanced system of needs and services. A man who exercised his craft, that is who exerted the δύναμις which nature had given to him, provided a service rather than set out to boost production as much as possible.[39] Such a "Weltanschauung" in which the words 'static' and 'balance' play an essential role, is not conducive to a mentality that wants to subdue nature and subsequently indulges into the constructing of complicated machines by means of which he can boost his production.[40]

[38] Vernant, *op. cit.*, 214 aptly comments: "Dans sa production, l'artisan voit - - - sa propre activité *se naturaliser*" (italics are mine, H.W.P.). In early Greek medicine τέχνη denotes the whole medical activity. The physician aims at restoring the δικαία φύσις. There is a distinct aversion against the use of instruments and a clear preference "möglichst nur die Hände zur Hilfe zu nehmen; und immer wieder wird das "Naturgemässe" (κατὰ φύσιν, δικαιοτάτη φύσις) hervorgehoben und gefordert" (F. Kudlien, *Wissenschaftlicher und instrumenteller Fortschritt in ihrer Wechselwirkung in der antiken Chirurgie*, Südhoffs Archiv für Geschichte der Medizin und der Naturwissenschaften 45, 1961, 329 ff. esp. 330). Those *mēchanēmata* which are accepted owe their acceptance to their being old and κατὰ φύσιν. Technē does not tame φύσις, it obeys; cf. G. H. Knutzen, *Technologie in den hippokratischen Schriften* Περὶ διαίτης ὀξέων, Περὶ ἀγμῶν, Περὶ ἄρθρων ἐμβολῆς (Abh. Akad. Mainz, 1963, nr 14), *passim* and Lämmli, *op. cit.*, 36/37. In later Hellenistic times instruments are increasingly used in orthopedic chirurgy: "Spezialmaschinen - - - alle von komplizierten, technisch hochentwickelten Bau; man spürt das Streben nach immer grösserer technischer Vervolkommung" (Kudlien, *loc. cit.*). Oribasius' 49th book is the main source for this phenomenon. A. G. Drachmann, *op. cit.*, Index s.v., discusses the main medical 'machines'. It is presumably not fortuitous that this development occurs simultaneously with the inventions of the Alexandrian engineers. The physician was enough of a *technitēs* to be attracted by their experiments and constructions.

[39] Cf. note 36.

[40] An important passage on the popularity of *technē* in Athens is provided by Thuc. I. 142 where Pericles is said to be confident about Athens' chances in the war against Sparta because "all that relates to the navy, is a matter of technē"; and technē is inseparable from continuous innovations (Thuc. I. 71). Remarkably enough technē here is military, naval 'technique'; the 'republic of the marines' shows great flexibility of mind; it experiments with new naval techniques; but the flexibility of the 'republic of the marines' (a variation on Max Weber's version of the Greek polis as an association of warriors)

Plato and Aristotle had the odd idea that an artisan should only exchange his products for those of his colleagues. Exchange within the limits of a man's natural need was according to nature. To produce for a market was *chrēmatistikē* and therefore despicable.[41] It seems improbable that the leading sophists and the technitai themselves would have subscribed to this kind of arm-chair wisdom. "Time is the costliest item of expense" is reported to have been a sophist's saying;[42] artisans and business-men are unlikely to have rejected the wisdom of "pecunia non olet". However, the crucial point is: which methods have been used in order to make more money? The probable answer is that the production had been stepped up by increasing the number of workmen and possibly by a kind of division of labour.[43] Technological devices which had

does not include a kind of alertness for *technological* innovations in the field of *production*. The republic of the warriors is not a republic of 'technological' producers. Cf. P. Vidal-Naquet, *art. cit.* (see note 35 above), esp. 171/2, 175 f. An equally interesting, though much later piece of evidence is provided by the sacred law of Antiochus of Kommagene who had built and fortified his city and palace and had improved the water supply for his subjects: "Οπλα, ὄργανα and μηχανώματα have contributed to that; they are the instruments of the τέχναι εὐανδρείας. There is a strong emphasis on craftmanship and its *ethical* and aesthetic implications; once again the *productive* aspect of τέχνη has been neglected (cf. H. Dörrie, *Der Königskult des Antiochos von Kommagene im Lichte Neuer Inschriften-Funde*, Göttingen 1964, 42/3).

[41] Aristotle, *Politica* 1257 a.6; 1258 a 10; cf. also *Eth. Nicom.* V. 5.6 ff. with Ed. Will's commentary in Revue Historique 212, 1954, 209 ff. (*De l'aspect ethique des origines de la monnaie grecque*) where Will anticipates many of J. P. Vernant's views on the Greek ideas about labour. Plato's and Aristotle's criticism on market-trade implies that the latter was a common phenomenon in 4th century Athens. K. Polanyi's thesis (in Karl Polanyi-Conrad Arendsberg-Harry W. Pearson, *Trade and Market in the early Empires*, Geneve, Illinois 1957, ch. V; now also available in G. Dalton (ed.), *Primitive, Archaic and Modern Economics* (Essays of Karl Polanyi, Anchor Books, New York 1968), 178 ff.), that 6th and 5th century Greece hardly knew what market-trade was and that a market-economy was non-existent is untenable. See G. E. M. de Sté Croix's remarks in Econ. Hist. Review, 2nd series, XII, 1960, 510-512. This does not, of course, detract from the great value of the conceptual framework built up by Polanyi for the study of the ancient economy.

[42] Diels-Kranz[6], *Fragm. der Vorsokr.*, (Antiphon), fragm. 77.

[43] In a wellknown passage (*Cyropaedia* 8.2.5) Xenophon tells us that in a small village "the same man makes couches, doors, ploughs and tables and often he even builds houses, and still he is thankful if only he can find enough work to support himself. In big cities, however, one trade can easily support one man, because the demand is bigger. A man specializes in shoe-making

made production both cheaper and quicker have not been applied.

Even if Protagoras and the other authors I mentioned above had had a genuine interest in mechanical technology (quod non!), it may be doubted whether they could have dominated the scene in opposition to a great many other philosophers who took an unfavourable view of applied sciences. The burden of philosophy weighed down heavily on ancient science. Many adhered to Plato's view that those philosophers who employed mechanical aids and arrangements constructed from them for the solution of geometrical problems, should be despised.[44] The philosopher relied on his λόγος; experiments were too often welcomed only inasmuch as they confirmed preconceived theories.

There was "clear, almost total, divorce between science and practice".[45] Anaxagoras' view that nature should be exploited by

and even that trade is split up in several other operations; cutting, sewing, assembling". It is true, Xenophon's purpose is to show that specialization (division of labour) improves the *quality* of the final product. But in X's text there is a close correlation between the volume of the demand and the subsequent division of labour ("enough work, bigger demands"). Is it misleading to argue that *the entrepreneurs* introduced specialization in their workshops because they wanted to satisfy an increasing demand? I would not argue, of course, that division of labour was practiced on a large scale throughout the ancient world for that purpose; but it may just be possible that in a few large centres, like Athens, it has been introduced in some branches of 'industry'. Finley's (*art. cit.*, 38) and Vernant's (*op. cit.*, 211-212) views on this passage were anticipated more than 40 years ago by H. Bolkestein, whose interpretations are now easily accessible in the English translation (*Economic Life in Greece's Golden Age*, Leiden 1958, 59-60) of his original Dutch study from 1923.

[44] Plutarch, *Life of Marcellus*, cap. 14. It has been generally assumed that the tunnel of Eupalinos on Samos was the result of practical application of Pythagorean geometry. A recent study (J. Goodfield-St. Toulmin, *How was the tunnel of Eupalinus aligned*, Isis 56, 1965, 46 ff.) suggests that the problem facing Eupalinus was one of *practical* engineering rather than one of geometrical theory. The tunnel was in fact built along one of the few lines by which one can climb up the rugged hillside; probably a series of posts on the ground was the line of constant direction across the mountain. A vertical shaft just outside the ancient entrance, through which light came down, possibly enabled the builder to keep to the line inside the tunnel; cf. the amusing story about the construction of a tunnel which should carry water through a mountain, in Roman Mauretania in the 2nd century A.D. (CIL VIII, 2728). A Roman military 'engineer' had planned the operation but in his absence the two crews who worked from opposite sides, had failed to meet.

[45] M. I. Finley, *art. cit.*, 32; for a brief account on the basic characteristics of ancient science see W. J. Verdenius, *Science Grecque et Science Moderne*,

man for his own benefit has been overshadowed by the Platonic preference for a respectful attitude towards nature, as exemplified by the famous Delphic answer to the Cnidians who tried to cut a canal through their peninsula: "Zeus would no doubt have made your peninsula an island had he wanted to".[46] This mentality was

Revue Philosophique 152, 1962, 319 ff.; cf. also F. Jürs, *Bemerkungen zum naturwissenschaftlichen Denken in der Spätantike*, Klio 43-45, 1965, 381 ff. There is an endless discussion about whether the Greeks were or were not "experimental" (cf. Lämmli, *op. cit.*, 144/5). Neugebauer writes about the modern myth that the Greeks developed theories without resorting to experiments (*The Exact Sciences in Antiquity*, Providence 195, 152). He points to Galen and Ptolemaeus, others add Philoponus who argued against the doctrine that the speed of a falling body is proportional to its weights: "this is completely false; and this may be confirmed more forcibly by actual observation than by any sort of verbal demonstration" (cf. G. E. R. Lloyd, *Experiment in early Greek Philosophy and Medicine*, Proc. Cambr. Phil. Soc. 1964, 50 ff., esp. 62); but it may still be true to say that the ancient experimental method was rudimentary and non-systematical and that experiments were rarely the starting point for modifying existing theories and hardly ever led to new conceptual schemes. Cl. Preaux, *Sur la stagnation de la pensée scientifique à l'époque Hellénistique*, Americ. Studies in Papyrology (Essays in honour of C. B. Welles) I, 1966, 235 ff., has recently shown how Aristotle stuck to old conceptual schemes and opposed the new theory of heliocentrism, put forward by others on the basis of systematic observations of the moveme ıts of the planets, *for moral and emotional reasons*. This attitude did not prevent him from criticising the Pythagoraeans for not adapting their reasoning to observed facts! O. Gigon has recently emphasized Aristotle's failure to link mathematics with physics and biology to make ancient science more exact and thereby to create the possibility of jumping from theory to technical applications (*Plinius und der Zerfall der antiken Naturwissenschaft*, Arctos IV, 1966, 23 ff.; cf. Lämmli, *op. cit.*, 61/2 and 144, note 335). Even an eminently practical scholar like Heron of Alexandria does not seem to have approached his mechanical problems by calculation. He tried empirically to make effective machinery by combining the five basic machines (wheel + axle, lever, pulley, wedge and endless screw) but he could hardly compute machinery (cf. R. J. Forbes, *The Ancients and the Machine*, Arch. Intern. d'Histoire des Sciences, 28, 1949, 919 ff., esp. 921). Most recently G. E. R. Lloyd has offered a very subtle interpretation of *Plato as a Natural Scientist*, JHS 88 (1968), 78 ff. In spite of Lloyd's subtlety I still feel that Timaeus 68d is strong evidence for Plato's dislike of experiments. There is a wide gap between God, Who has knowledge and power, and man who basically is and will remain capable of finding out the truth. It may be true that Plato, and for that matter other philosophers as well, occasionally did not object to certain concrete experiments (cf. Lloyd's discussion of the Timaeus-passage) but his over-all attitude certainly was and has been felt to be detrimental to the making of *systematic* experiments.

[46] Herodotus I, 174; also VII, 22 and 35; VIII, 97; cf. Verdenius, *art. cit.*, 330; Lämmli, *op. cit.*, 47/8, 62 and 121, note 250; Fr. Krafft, *art. cit.* (see note 51), 8/9.

not conducive to bridging the gap between 'science' and practical applications. Experimental philosophers-scientists like Straton of Lampsacus were rare and their experiments did not result in practical inventions.[47] Admittedly, canals and tunnels have been made in antiquity, in spite of the Delphic answer. However, the number of canal-projects known to us is not large: often they served military purposes and were conceived and supervised by military experts, not by philosophers. Eupalinus' tunnel, as already noted in note 44, also was a product of practical engineering, not of applied science. And these 'attacks' on nature, it may be added, served anything but labour saving purposes. Ca. 110 A.D. Pliny suggested to dig a canal near Nicomedia in order to obviate expensive and laborious landtransport. Long ago a Hellenistic king seems to have begun a canal in the same area but it was never finished and its exact purpose was unknown to Pliny. Pliny's project was to be supervised by military engineers. The project has never been executed and when Justinian revived it 450 years later, it again shared the fate of Trajan's proposal. In general it seems true to say that in the Roman Empire canals, tunnels and aquaducts even if they did not serve military purposes have been frequently designed by military technicians, not by philosophers interested in applied science. Significantly the lack of interest of the latter in these practical matters led the engineers and architects to appropriate the name 'philosophus'. The other side countered by calling them '*mēchanici*' and their trade a *technē*. When Procopius attributes *sophia* to the architect of the St. Sophia, he hastens to add "*sophia*, h.e. the so-called 'mechanical' *sophia*"!

In the 4th century A.D. we hear about a project of a Roman governor of Asia Minor to dig a canal in the delta of the Meander near Miletus in order to obviate the coming into existence of a big marshy area and the silting up of Miletus' ports. To the contemporary rhetor Himerius we owe a fragmentary report on these activities. The sources do not say whether the governor availed himself of the services of military or civil experts but since we happen to know that in the late 4th century *comites* are attested which are explicitly called '*mechanicus*' and that one of these

[47] Lämmli, *op. cit.*, 62.

supervised the building of a bridge over the Cydnus river in Tarsus in S.E. Asia Minor, it is by no means impossible that our governor has relied on the skills of a similar comes. Whatever the truth is, two aspects deserve to be underlined in this affair. First, Himerius describes the operations in terms of a *restoration* of the *physis adikoumenē*. Second, he calls them 'sophismata', 'wise inventions', realized by the 'wise hand' (*sophē cheir*) of the governor. Once again 'engineering' is correlated with sophia and, more important, these engineering activities, supervised by the governor but executed by technical experts, aim at *restoring* nature, not at attacking and subduing it.[48]

Plato's above-mentioned criticism implies that there were philosophers who did combine their abstract thought with the practice of mechanics. The author of the Peripatetic treatise "Mechanical Problems" was one of them. He was struck by the miraculous fact that by the use of special instruments a small force under certain conditions can move a larger weight. In this respect he shares the mentality of the sophist: the latter made "the weaker cause stronger" (*ton hēttō logon kreittō*) through his rhetorical *technē*, the former used his mechanical *technē* to bring about that "the smaller and weaker forces become superior to the bigger and stronger" (*ta elattō kratei tōn meizonōn*). This achievement was *thaumasion* (strange, astonishing), and the author's main purpose was to *explain* this. He did so by representing all mechanical processes as the result of a number of basic instruments (lever, pul-

[48] F. G. Moore, *Three Canal Projects*, AJA 54 (1950), 97 ff.; J. Sasel, *Trajan's Canal and the Iron Gate*, JRS 63 (1973), 80 ff.; Pliny, *Ep.* X. 41/42, 61 with Sherwin-White's commentary ad locum; for 'philosophus' as 'building expert' or 'technician' cf. R. MacMullen, *Soldier and Civilian in the later Roman Empire*, Cambridge (Mass.) 1967², 34; for the Himerius' passage and a related epigram cf. L. Robert, *Laodicée du Lycos, Les Inscriptions*, Paris 1969, 348/9; G. Downey, *Byzantine Architects. Their training and Methods*, Byzantion 18 (1948), 399 ff. When in the first century A.D. Heron of Byzantium attempts to show that the philosophical ideal of *ataraxia* ("calmness') has been realized thanks to the efforts of the military engineers who build artillery and thereby contribute to the stability of the pax Augusta, he explicitly refers to ἡ διὰ τῶν ὀργανῶν φιλοσοφία: the engineer is a philosopher in its own right, next to (and actually even rising above) the 'theoretical' philosopher, who διὰ τῶν λόγων investigates the problems of ataraxia; cf. my article in Acta Historiae Neerlandica II (1967), 4, with note 4, 5, and Fr. Krafft, *art. cit.*, 13.

ley, windlass, wedge). In their turn these instruments were all said to derive from the circle. "Cette démonstration fixe d'avance les limites au delà desquelles cette *technē* ne doit pas s'aventurer".[49] But there is something else which even more precluded the development of a technē-without-limits. The Peripatetic author defined *technē* as something which in a way is *para physin* (contrary to nature) and in doing so he perhaps unconsciously showed that same respectful attitude towards nature which was on record in the Delphian oracle to the Cnidians. In his definition of *technē* the author apologized, so to speak, to nature for his work. Lämmli rightly says: "Ganz besonders eindrücklich präsentiert sich die den Griechen hemmende Scheu vor der Physis, wenn selbst der Verfasser . . . der "Mechanischen Probleme" die Mechanik als eine Art Paraphysik definiert, mit deren Hilfe es durch die "unnatürlichen" Mittel der Technē *para tēn physin* gelingt, die Natur gewissermaszen zugunsten des menschlichen Nutzens zurechtzubiegen und zu überlisten".[50]

Here it is perhaps appropriate to add that, as Fr. Krafft (see note 51) has recently pointed out, because of this notion of *technē* and *mēchanē* being un-natural means to 'trap' (German: überlisten) nature, ancient technique (mechanics) did not become part of physics in antiquity. It remained, as Pappus (4th century A.D.) shows in the first chapters of the eigth book of his Synagogē, a sort of applied mathematics and suffered from the traumatic idea that the 'machines' which it devised helped people to subdue nature by tricky operations. It was Galilei who maintained that the mechanical processes in fact were natural processes and thereby inaugurated a new philosophy about the relation between mechanics and nature which resulted into the incorporation of mechanics into physics (cf. also Lämmli, *op. cit.*, 65).

Heron of Alexandria adopted this coherent system of basic instruments of the Peripatetic author. He merely added a number of rather primitive calculations to solve the problem of moving a heavy burden with a small force by means of these instruments.[51]

[49] J. P. Vernant, *op. cit.*, 236.

[50] Lämmli, *op. cit.*, 64/5; according to Pappus, Collectio VIII, 1-3, the mechanikē technē deals with phenomena *kata physin* and *para physin* (cf. Fr. Krafft, *art. cit.* (in note 51), 3/4, 9/10).

[51] Outside the realm of the 5 basic instruments in the field of ballistic and

It is worthy of note that Vitruvius in the introduction to his tenth book on machines preached without any misgivings the following message: "all machinery is generated by Nature and the revolution of the universe guides and controls . . Our fathers . . took precedents from Nature; imitating them and led on by what is divine they developed the comforts of life by their inventions".[52] Nature was regarded as sovereign; the engineer respectfully followed her and during this journey drew strongly on his *'logismos'*. It is true, *empeiria* was not absent but it was a matter of hesitating observations. The two rarely joined in order to formulate exact physical laws. Measuring and calculating were the undeveloped spots in the conceptual system of the philosopher-engineer. Vernant has acutely observed that in ballistics and pneumatics the forces of nature were hardly measured at all. The principles of energy stored in compressed air and steam were well-known, but "neither the machines nor the forces they harness, nor the effects have been calculated".[53] As a result, all pneumatic instruments and machines remained toys. *Logismos* could not control them.

However different the mentality of ancient scientists and engineers may have been from that of their post-Descartean counterparts, it remains a fact that by combining theory and practice [54]

pneumatic machines the powers of physis are hardly calculated at all. Such machines are θαύματα: "La machine réalise donc une maîtrise sur des forces physiques qui echappent au controle rigoureux de la raison" (Vernant, *op. cit.*, 240). According to Drachmann (*op. cit.*, 91) Hero did not know how to compute the power of the endless screw. [On Hero see now Fr. Krafft, *Kunst und Natur. Die Heronische Frage und die Technik in der klassischen Antike*, Antike und Abendland 19 (1973), 3 ff.]

[52] Vitruvius, *De Architectura* X. 1.4.

[53] Vernant, *op. cit.*, 240; cf. also note 51 above.

[54] Cf. *e.g.* Pappus, apud Cohen-Drabkin, *op. cit.*, 183-4; "The mechanicians of Hero's school tell us that the science of mechanics consists of a theoretical and a practical part. The theoretical part includes geometry, arithmetic, astronomy and physics, while the practical part consists of metal-working, architecture [or rather 'construction' see G. Downey, Byzantion 18 (1948), 107] carpentry, painting, and the manual activities connected with these arts. One who has had instruction from boyhood in the aforesaid theoretical branches, and has attained skill in the practical arts mentioned, and possesses a quick intelligence, will be, they say, the ablest inventor of mechanical devices and the most competent masterbuilder". Pappus summarizes his views as follows: "Such, then, is the nature of mechanics, which is both a science and an art" (Cohen-Drabkin, 185); see also Vitruvius I. 1.1-2 where the author advocates a combination of theory and practical skill for the architect.

the ancient engineers [55] produced a number of remarkable devices. Descriptions of them are available in their treatises and in that of Vitruvius. The following points which illustrate the interplay between technology and society deserve mention:

(1) Of the five main powers wedge, lever, pulley, windlass and screw the first four were undoubtedly known and used in practise long before the theoreticians began to write about them. The author of *Mechanical Problems* mentions the compound pulley in connection with house building.[56] He points out that by means of compound pulleys and windlasses great weights are moved in the building-trade. B. Gille [57] notes the use of the windlass and the pulley from the 6th century onwards, both in the theatre (*deus ex machina*) and for loading and unloading vessels. The lever was used in oil-presses and in the *kēloneion* (swing-beam), the Egyptian 'shadouf' consisting of a bucket attached to the end of a lever.[58] The *kēloneion* is on record in an Athenian inscription from the 5th century.[59] One gets the impression that in many respects the artisans/craftsmen had already helped to achieve operations which were otherwise impossible or possible only by excessive effort. It may have been that the 'engineers' improved the devices used by the craftsmen, but I see no way of determining exactly which contributions were made by whom.

(2) Even if we assume that the devices used for lifting heavy objects were considerably improved by the 'engineers', we must proceed to point out that they were by no means used on a large scale. Vitruvius [60] contrasts, e.g., buildingcranes and watermills

[55] Forbes, *Studies* VII, 140 asserts that the Peripatetic philosopher Straton of Lampsacus who experimented with a vacuum space (Cohen-Drabkin, 245 ff.), wrote a book on mining-tools and techniques. This would be a rare and therefore a most welcome example of a philosopher who was interested in tools and wrote about them. However, in F. Wehrli's interpretation (*Straton von Lampsakos* (Basel 1950, 70)) the title of Straton's lost work Περὶ τῶν μεταλλικῶν points to a pharmakological treatise. J. Schnayder, *Technologisches in den Werken Theophrasts*, Eos 52, 1962, 259 ff. was inaccessible to me.

[56] *Mechanical Problems*, Problem 18; cf. A. G. Drachmann, *op. cit.* (see note 30), 15, 16.

[57] B. Gille, *A History of Technology*, vol. II, Oxford 1956, 630.

[58] Forbes, *Studies in ancient Technology*, II, 32 ff.

[59] Hesperia 30, 1961, 26 ff.; for the κηλώνειον in Egyptian agriculture see A. Swiderek, *La propriété foncière privée dans l'Egypte de Vespasian et sa technique agricole d'après P. Lond.* 131 *recto*, Wroclaw 1960, 58 f., 84 f., 96 f.

[60] Vitruvius X, 2; X, 1, 6; cf. my article *Technology and Society in the Graeco-Roman World*, Acta Historiae Neerlandica II, 1967, 1 ff., esp. 10, note 2.

which "seldom come to hand" with objects "we have in hand everyday" such as chariots, wagons, millstones and bellows. Since his work is intended to be read by specialized readers, we may perhaps assume that Vitruvius believed that cranes and watermills were still only rarely used. For ordinary houses of one story, no cranes were used, according to Drachmann. "They had to be procured for temples and public buildings".[61]

(3) Both Hero and Vitruvius are convinced of the great use, nay, even necessity of their devices.[62] They do, however, not recommend them to achieve greater productivity or economy of effort.[63] Hero believes that his devices will be "of great use in the handling and lifting of burdens".[64] But it is worthy of note that a special device described and constructed by Hero to move a weight of 1000 talents with a power of 5 talents belongs to the realm of theory.[65] Neither his complicated, if labour-saving, cogged wheel mechanism nor his device that resulted from a combination of the lever, the pulley, the axle and wheel and the screw, were more than theoretical examples.[66] In the case of the "baroulkos" it is important to note that at the end of its description Hero added the specific advice: "if we do not want to use toothed wheels, we wind ropes round the axles and wheels".[67] Drachmann [68] aptly remarks that that was the actual method, as described by Vitruvius (bk 10, 2). I pass over the technical details of Vitruvius' description of 'hoisting machines' in 10, 2 but would like to emphasize his final sentence: "but if a greater wheel is placed either in the middle or in one of the outer ends, it may have a swifter effect on the work without a capstan by

[61] Drachmann, *op. cit.*, 145; cf. Forbes, *art. cit.* (see note 45), 922/3: "A certain amount of machinery such as cranes was introduced in the building crafts but no efficient solution for hauling heavy materials was found".

[62] Vitruvius X, 1, 2; X, 6, 4 ("infinitae utilitates", for water-drawing machines); 7, 4 (utilia et necessaria); 9, 7; Hero, *Mechanica* I, 34 (Drachmann, *op. cit.*, 49); II, 4-5 (Drachmann, 55 ff.).

[63] This point, made by Finley (*art. cit.*, 34/5) for Vitruvius, is valid for Hero as well.

[64] *Mechanica* I, 34 (Drachmann, *op. cit.*, 49).

[65] *Mechanica* I, 1; II, 21 (Drachmann, *op. cit.*, 22 ff., 82 ff.).

[66] *Mechanica* II, 29 (Drachmann, *op. cit.*, 89 f.).

[67] *Mechanica* I, 21 (Drachmann, *op. cit.*, 83).

[68] Drachmann, *op. cit.*, 32.

treading men".[69] Archaeological reliefs show that man walking in a treadmill did in fact power the ancient buildingcrane.[70] Hero and Vitruvius were both convinced of the use and necessity of some sort of device to be used for lifting heavy blocks. The lifting of heavy blocks to the top of a building indeed is an operation which would "otherwise (be) impossible or possible only by excessive effort".[71] But instead of using a capstan and saving manpower, Vitruvius preferred the treadingmill. As to the endless screw, engaged in the teeth of a wheel, and enabling a single man to lift a 1000 talents easily, it is appropriate to remember Drachmann's words: "At this time the endless screw was not used for cranes and hoists. Instead of multiplying the engines the contractors would multiply the manpower; what one worker could not do was done by ten or twenty or fifty workers pulling together under the command of an overseer".[72]

In this context the wellknown anecdote told by Suetonius of Vespasian [73] deserves a place: "When an engineer offered to bring some large columns to the Capitol for a small fee, Vespasian rewarded him substantially for his invention but did not have the work carried out, arguing that the engineer should not let him take the bread out of poor people's mouths". Forbes [74] assumes that the mechanism referred to was one driven by water power, but there is nothing to this effect in Suetonius' text. It is equally possible that our mechanic had constructed a complicated cogged wheel system of the kind invented by Hero. However this may be, it seems clear that in this instance a social factor, viz. excess manpower, impeded the use of a labour-replacing 'machine'.

The above picture holds good for the methods and devices used

[69] Vitruvius 10.2.7 (Drachmann, *op. cit.*, 146).

[70] See the illustrations in the *Oxford History of Technology* II 637 (fig. 578), 660 (fig. 603).

[71] "All in all, it is correct to say that for Vitruvius the sole aim of technical advance (apart from aesthetic considerations) is the achievement of operations which are otherwise impossible, or possible only by excessive effort" (M. I. Finley, *art. cit.*, 35). I had made the same point simultaneously; see Acta Historiae Neerlandica II, 1967, 24; cf. Vitruvius X, 1, 5 who writes that without the construction of wagons and ships transport would have been impossible.

[72] Drachmann, *op. cit.*, 91.

[73] Suetonius, *Life of Vespasian*, 18. [cf. now M. I. Finley, *The Ancient Economy* (London, 1973), 75].

[74] *Studies* —, II, 96-7.

for raising water.[75] Just as the ancients were sensible and practical enough not to have their heavy marble blocks pushed forward on a mounting road by manpower,[76] similarly they did not stick to the bucket attached to a rope. This primitive first stage was followed by a combination of bucket and lever (the 'dia cheiros' method of the shadouf).[77] In the 3rd stage pots or hollow compartments were attached to the rim of a vertical waterwheel geared to a horizontal wheel turned by man or animal. This method presupposes the invention and development of the gear-wheel, probably to be dated to the beginning of the Hellenistic era.[78] We first encounter the 'sakiyeh' in a second century papyrus. Whether it became a frequently used device in the Roman period [79] is hard to tell. It may be true for Egypt but Vitruvius [80] mentions the manpower-driven waterwheel ("wheel of pots" and "compartment-wheel" in Forbes' terminology) in his discussion of *rarely used* machines (see above).

However this may be, the so-called Archimedean screw, driven by manpower (viz. with the feet and not with the help of a crank, a device unknown to ancient engineers),[81] was in fact used in Egypt

[75] Forbes, *Studies*, II, 32 ff. has an excellent discussion of the various 'Methods of raising water'.

[76] On the use of sleds for dragging loads see Hero, *Mechanica* I, 21-22 (Drachmann, *op. cit.*, 47) and the reconstruction in Revue Archéologique, 1966, fasc. 2, 243 ff., esp. 270/1.

[77] See above p. 22), with note 58 and 59.

[78] Forbes, *Studies* —, II, 32-34; on the gear-wheel see Drachmann, *op. cit.*, 203.

[79] So Forbes, *loc. cit.*; cf. M. Schnebel, *Die Landwirtschaft im hellenistischen Ägypten*, München 1925, 71 ff. and A. Swiderek, *op. cit.*, 84 ff. and 96 ff., who shows that the ὄργανα used in *P. Lond.* 131 were shadoufs and Archimedean screws (and not sakiyehs). The sakiyeh was technically more complicated than the screw but had the advantage that it could be driven by animals; the screw was driven by manpower, *viz.* human feet. In Egypt the screw seems to have been used more widely than the sakiyeh. Manpower was apparently no problem; nor were those devices applied primarily to save manpower. The objective was rather to avoid the extreme difficulty of manual methods. In fact Vitruvius (X. 4) does not even mention the possibility of an animal-driven waterwheel; he has it turned by treading-men.

[80] Vitruvius X, 4; cf. also Artemidoros, *Oneirocriticon* I, 48, who mentions people who have been condemned to work as miserable bailers on a treadmill; cf. R. MacMullen, *Social History in Astrology*, Ancient Society 2, 1971, 110. Artemidoros clearly implies the existence of such treadmills but says or implies nothing about the intensity of its use.

[81] Cf. Forbes, *Studies* — II, 38; on the crank see also L. White, *Medieval Technology and Social Change*, Oxford 1963, 103 ff., 160, 167.

for purposes of irrigation. Diodorus [82] adds that Archimedes was credited with the invention of this screw and that it was also used for draining mines: "An enormous amount of water is thrown out, to one's astonishment, by means of a trifling amount of labour". In addition to screws large compartment-wheels were used in mines; they were worked by treadmills, moved by two, three, or even more men. It was only in medieval times that animal power was used underground for draining purposes.[83] Antiquity surely passed the stage of having each bucket of water carried by individual men.[84] There was an awareness that some methods for raising water were labour-saving, though admittedly this was an 'astonishing' fact to the historian Diodorus. This awareness goes one step further than, e.g., Cato's advice not to waste labour and to keep slaves occupied all the time. But it does not at all go all the way to the fourth stage in which manpower becomes redundant.

To this stage belong the waterwheels, which could be used both for raising water and providing power to grainmills, and the windmill. The latter has been described by Hero, and Drachmann has shown, against Forbes, that Hero's description is nót a later addition to the manuscript.[85] Waterdriven grainmills, though known in the 1st century B.C., were never used on any significant scale in antiquity. Everybody knows the stock-examples: the Arles-mill (3rd/4th century); the mill at Tournus; and the early Byzantine mill on the Ianiculum at Rome.[86] The record is late and hardly impressive; the windmill had never been used in antiquity. To

[82] Diodorus I. 34; V. 37. The words "to one's astonishment" are significant. Ingenious devices, like the waterraising-screw, were θαύματα (miracles); see above p. 20/1 and note 51; for the Archimedean screw see also Strabo, XVII, 1.30.

[83] For animals working a chain -pump underground in medieval time see Forbes, *Studies* —, VII, 218.

[84] Though handbailing in relays remained common just as the transport of ore to the surface with relays of slaves; cf. Forbes, *Studies* —, VII, 211 (quoting Pliny, *N.H.*, 33, 21, 71) and 208. From Forbes' studies one gets the impression that in the Hellenistic-Roman period in rich mines both drainage machinery and hoisting apparatus have been increasingly used. But they did not oust the older methods and, as said in the text, were not ousted themselves by animal-power. Once again the ancients went halfway to avoid the extreme difficulties of manual methods.

[85] Drachmann, *op. cit.*, 206 (with further references).

[86] See my survey in Acta Historiae Neerlandica II, 1967, 11 ff.

explain the rare and late use of grainmills scholars have pointed out that such mills require a constant and abundant supply of water and that this requirement was rarely met. I do not think this explanation at all satisfactory,[87] but even if it were, it would not suffice to account for the neglect of the windmill. Wind is available everywhere, though I do realize that not each country is as windy as my own.

Another example of labour-saving value is the by now wellknown mechanical reaper, described by Pliny the Elder and Palladius and recognisable on a couple of archaeological reliefs.[88] Both the literary evidence and the reliefs show that its use was probably restricted to the large estates in Northern Gaul; Palladius and Pliny imply the labour-saving aspect of this machine. Palladius adds that "this machine is useful on open places or where the ground is level and in areas where the straw has no economic value". The latter information has been particularly emphasized by scholars. White argues that "special conditions prevailing both in regard to the size of agricultural units and to supplies of manpower tended to favour the use of labour and time-saving methods of production".[89] To lump two such entirely different factors together, in my view, creates confusion. Open plains, where the ground is level, surely were available in a great many areas outside Gaul (Greece, Egypt, North-Africa, Sicily, Italy). Pliny admittedly says that the reaper was used on Gallic latifundia but this is by no means tantamount to saying that it could be used on latifundia *only*: and even if that were so, the machine could have been used on a large scale outside Northern-Gaul. I do not see how the "growth habit of autumn-sown wheat elsewhere in the Mediterranean areas" [90] could have worked against the use of the reaper. Could the Gallic specimen not have been adapted to different situations? In other words, the manpower argument seems to me an important, though not a monocausal

[87] *Art. cit.*, 13, note 2; see in the same sense Finley, *art. cit.*, 36; Kiechle, *op. cit.*, 126/7.

[88] The best and most recent discussion is to be found in K. D. White, *Agricultural implements of the Roman World*, Cambridge 1967, 157 ff.; see also id., *Gallo-Roman Harvesting Machines*, Latomus 26, 1967, 641 ff.; *Roman Farming*, London 1970, 182/3, 448/9, 452/3.

[89] White, *op. cit.*, 172.

[90] White, *op. cit.*, 171.

argument (see further down p. 30/2 for the problem of the mentality: the barbarians are credited with a flair for the invention of technical devices by a late 4th cent. A.D. author!). The literary sources mention the reaper within the context of 'raritas operarum' and the saving of 'hominum labores' by means of 'unius bovis opera'.[91]

Kiechle has recently questioned the explanatory force of the manpower argument. He maintained that according to Pliny the reaper was already used in Northern Gaul in the first century A.D. and that at that time there was no question of shortage of manpower in the Roman Empire.[92] But this does not mean that special circumstances cannot have operated in Northern Gaul. The growth of urban agglomerations in that area, which caused a drift from the land, may have been one of them. And Kiechle himself casually suggests that the death and enslavement of a great many people in the war against Caesar, resulted in a shortage of manpower which in its turn provoked the invention of this machine.[93] Thus Kiechle himself thinks in terms of special circumstances which may have brought about a shortage of labour in Gaul.

In general it is the absence of the labour-saving devices like waterdriven grainmills and reapers in the greco-roman world which is to be explained. The few examples of such devices being used in practice are just exceptions to confirm the general rule.[94]

Two interdependent factors can be mentioned here. First there is the factor of the general adequacy of the supply of labour. I expressly avoid the term 'slavery' here. Kiechle once more has pointed out that the theory that slaves were too stupid and disinterested to be able to manage technologically advanced devices

[91] Cf. White, *op. cit.*, 170; and my *art. cit.*, 15; on the 'Gallic reaper' see now M. I. Finley, *The Ancient Economy* (London 1973), 115 with note 54.

[92] Kiechle, *op. cit.*, 130 ff.

[93] *Op. cit.*, 134.

[94] I cannot subscribe any longer to the view, expressed in my *art. cit.*, 16, that the use of the waterdriven grainmills in the later Roman Empire e contrario confirms the theory that the general availability of manpower was the essential factor leading to the neglect of labour-saving machines. If that view (and its implicit assumption) were valid, we should have to wonder why the use of these mills did not spread more widely and rapidly; see Kiechle, *op. cit.*, 173, note 16. In actual fact the implicit assumption that in the LRE labour was scarce may well be a modern theory rather than a reflection of what landowners themselves felt; see below p. 30.

cannot be supported.[95] The notion of the adequacy of the supply of labour, comprising both slaves and other forms of dependent labour and free labourers, is merely quantitative. Qualitatively slaves were not inferior to free craftsmen and, qualitatively, technology, in the sense of refined craftmanship, did advance, as Kiechle showed. Now Kiechle has recently criticized the view that ample availability of manpower can be used to explain the over-all absence of labour-saving devices in the ancient economy. First, he seems to suggest that during the Principate the labour-force may not have been plentiful but the evidence he produces—a passage from Pliny, *Ep.* 3.19.6—emphasizes the bad quality of the tenants and Pliny's ethical objections against the use of chained slaves and does not refer to the unavailability of slaves in general.[96] And even if it did, one text would hardly be a good basis for generalization.

Secondly, in Kiechle's view the private landowners can be shown to have been sharply aware of the costs of additional hired labour necessary for peak-periods in agriculture, especially during the harvest. Unfortunately at one place he uses this as an argument against the thesis that abundance of *slave-labour* prevented the adoption of labour saving instruments (p. 138), whereas at another and later place he talks about "Arbeitskräfte" in general.[97] We limit ourselves to the latter and first point out that Varro I, 53, adduced by Kiechle, above all shows that *normally* the landowner leased the *spicilegium* to a group of hired labourers and that only "if the '*spicae*' are few and the cost of labour high", the land should be pastured. In such cases only one should keep in view that the expense shall not exceed the profit. Labour costs are not a predominant factor. They are taken into account only in the exceptional case of the 'spicae' (ears left) being 'rarae' (few). Moreover, the gleaning itself is a minor, secondary operation. The harvest is the major thing and there is no mention of a notion of costly labour preventing the contracting of hired labour for that job. In other words: the notion of scarce and costly labour was marginal in the general mentality of the landowners and the agronomists.[98] But there is another and more interesting point.

[95] *Op. cit., passim*; cf. also P. A. Brunt, JRS 62 (1972), 155.

[96] *Op. cit.*, 133/4 and 173. [Cf. in the same sense H. Bellen, *Studien zur Sklavenflucht im Römischen Kaiserreich*, Wiesbaden 1971, 21, note 13].

[97] *Op. cit.*, 138 and 173.

[98] Cf. P. A. Brunt, JRS 62 (1972), 154.

Whenever the notion of scarce and costly labour appears in the agronomists in a discussion of the best way to do a specific agricultural job, the authors do not recommend the use of labour-saving devices, in an attempt to keep up maximal agricultural standards, but the application of the 'second best' agricultural method.[99] In this particular case the manpower-argument obviously cannot explain by itself why this marginal awareness of labour-costs did not lead to a search for labour-saving methods. Consequently we need another factor to explain the absence of these methods and I suggest that this factor is the 'mentality' of the leading social groups, esp. the estate-owners. This factor perhaps was the decisive element. The feeling that a labour-force was generally available may perhaps have contributed to the shaping of this mentality in the sense that, if occasionally the labour-supply unexpectedly turned out to be disappointing, this fact was accepted as such and a solution was looked for outside the realm of manpower. The use of the manpower-argument as a *monocausal* factor becomes somewhat questionable if one realizes that the industrial revolution did not quite take off in a period of scarcity of labour. On the other hand the 'case' of the later Roman Empire need not necessarily be an argument against the validity of the same argument. *We* may believe, with Boak, that there was a shortage of manpower in the L.R.E. but the essential point is that the late Roman estate-owners need not have had the same perception as Boak. After all many people placed themselves as *colonus* under their *patrocinium*; and they successfully managed to keep their *coloni* out of the army or other nonproductive branches. Now what does the above-mentioned mentality amount to?

We have already pointed out [100] that most ancient philosophers had strong objections to the practical application of scientific theories. Wellknown and particularly illustrative of this mentality is Archimedes' point of view as expressed by Plutarch: "he regarded the work of an engineer and every art that ministers to the needs of life as ignoble and vulgar".[101]

It would be unwise to project a priori the view of a small select

[99] Cf. K. D. White, *Roman Farming*, London 1970, 450.
[100] See above p. 16 ff.
[101] Plutarchus, *Life of Marcellus*, cap. 14; cf. Lämmli, *op. cit.*, 65.

group of philosophers onto the leading strata of society. Seneca's categorical condemnation of man's desire for material gain, in which progress in technology is said to be rooted (*Ep.* 90), is more likely to be a reaction against, than a reflection of, social realities. Greek and Roman aristocrats certainly have been dominated by profit-seeking motives. How otherwise are we to explain Aristotle's invectives against *chrematistikē*? However, to avoid falling into the trap of the time-honoured slogan "Human nature remains the same" [102] it is necessary to point out that *the way* in which that motive was satisfied is essential. I have no doubts that the ancient way was different from the post-Descartean and, if we may believe Lynn White, from the medieval way as well. Archimedes' view, I submit, was widely shared by the ancient upper-ten. It is the anonymous 4th century A.D. author of the pamphlet "De rebus bellicis", admirably edited and commented upon by E. A. Thompson, who provides the best evidence: "It is universally agreed that in the technical arts (among which we include the invention of weapons) progress is due not to those of the highest birth or immense wealth or public office or eloquence derived from literary studies but solely to men of intellectual power (which is the mother of every excellence), depending as it does on a happy accident of nature".[103] The literary-rhetorical, semi-philosophical pattern of education [104] was not conducive to a genuine interest in technology.

[102] See R. C. van Caeneghem's excellent article *Psychologische Geschiedenis*, Tijdschrift voor Geschiedenis 78, 1965, 129 ff., for a welcome discussion of the value of the slogan 'human nature remains the same'.

[103] E. A. Thompson, *A Roman Reformer and Inventor (being a new text of the treatise De rebus bellicis with a translation and a commentary)*, Oxford 1952, Preface, 4.

[104] In this respect it is worthy of note that the aristocracies which increasingly came to dominate political life in the Hellenistic-Roman city states counted many wellknown rhetors, sophists and philosophers among their members. Epigraphical (see *e.g.* M. N. Tod, JHS 1957, 132 ff. with L. Robert's comments in REG 1958, 197 f.; L. Robert, *Hellenica* IV, 115 ff.; XI-XII, 283, note 4, 485, note 1; id., L'Ant. Class. 35, 1966, 395 ff.; C. P. Jones, HSt Cl. Ph. 71, 1966, 205/13) and literary (*e.g.* Philostratus' *Life of the Sophists*) sources amply testify to this phenomenon which deserves a fully documented study. L. Robert has recently pointed out that the verbosity of a great many city state decrees from the Hellenistic-Roman period reflects the thorough literary-rhetorical training of the political leaders (REA 62, 1960, 325). An interesting study could and should be made of

The leading aristocratic families in the cities simply did not get into contact with the few advocates of applied mathematics and mechanics like Heron or Pappus and their followers; nor did they read treatises like the mechanical Problems or Pappus' Synagogē in which the will to design things even *para physin* overcame the awe of nature as shown by Herodotus' story about the Knidos-canal. Inasmuch such writings had any influence on practical life, they were read by architects and designers of war-machines. The late Roman 'comes' who functioned as 'mechanicus' (see above p. 18/9) supervised building-operations; others will have been active in the army. They were not by any standard typical representatives of the urban, landowning aristocracy. Heron of Byzantium may have called himself and his fellow-engineers "philosophers" but this does not alter the fact that the philosophers who appeared on the political scene in the greco-roman cities adhered to the kind of 'theoretical' philosophy, over against which Heron in the first paragraph of his Belopoiika in vain advocated the fundamental importance of his own "practical" philosophy - διὰ - τῶν - ὀργάνων (cf. above p. 19, with note 48). The same anonymous author contrasts this mentality of the Greco-Roman aristocracy with that of the barbarians, who are credited with a flair for technology and the invention of technical devices.[105] Is it entirely fortuitous that the mechanical reaper had been developed among "barbarian" frontier tribes? [106]

those typically rhetorical and philosophical terms which are on record in inscriptions (cf. *inter alia* L. Robert, *Hellenica* XIII, 177/8; id., Revue de Philologie, 1967, 11, note 2). E. le Roy-Ladurie, *Les Paysans de Languedoc* (Paris 1966) has explained the static character of the rural economy of Languedoc by pointing to "une immobilisme technologique — enveloppée pas toute *une série de blocages culturels*"; "sainteté" and "gloire" were more important than economic expansion.

[105] *Ibid.*, Preface 4: minime a rerum inventione, natura opitulante, habentur alienae: on the theme of the technological contributions made by the "barbarians" see L. White, Speculum 15, 1940, 141 ff.

[106] The same can be said about the wheeled plough, apparently, if we may believe Pliny, *N.H.*, 18.172, developed in Raetia; see K. D. White, *op. cit.*, 139/40 and L. White, *op. cit.* (see note 81) 42 ff.; cf. also P. R. L. Brown's interesting remarks in *The Later Roman Empire*, Econ. Hist. Review, 1967, 327 ff., esp. 336/7, on the failure of the Romans "to develop a "Northern" agrarian society, as an alternative to that of the Mediterranean" and in general on the *damnosa haereditas* which the Mediterranean world was for the rest of the Western Empire.

The economic component of the ruling class' mentality should not be neglected in this respect. To put it bluntly, the ancient economy was a prestige-economy, not an investment-economy. This statement finds, in my view, striking illustration in passages from the Roman agronomist Columella and the polymath Pliny the Elder. It would be demonstrably false to argue that the Roman agronomists—Cato, Varro, Columella—showed no sensitivity to profit-making. Their works are full of practical hints about the quality of the soil, the (non)-profitability of certain crops, the labour-forces to be used, etc.[107] However, M. I. Finley's words on Cato's agricultural advices deserve to be quoted: "All this is cheese-paring; it is not economic rationalism".[108] Finley also correctly pointed out that we would look in vain for a trace of, e.g., the Gallic reaper, the screw-press and the watermill in the manuals of Varro and Columella. It is particularly regretful that Prof. Martin has been unable to read his paper during this congress but even if it could be argued that the Latin agronomists were not only sensitive to but also dominated by consideration of economic rationalism,[109] this

[107] For Columella's sense of the profitability of a farm see *e.g.* I. 8 3 (the manager of an estate should keep in repair and store twice as many tools as the number of slaves required "for the loss in slave-labour exceeds the cost of articles of this sort"). Cf. K. D. White, *The Productivity of Labour in Roman Agriculture*, Antiquity 39, 1965, 102 ff. Columella knows that labour costs money. He has definite criteria to determine how many labourers were needed on an estate. Those labourers should be fully employed but there was no attempt to bring down their number and instead to use labour-saving machinery. For Columella the best method of threshing is with the flail: it is more economical of the grain than the treading out by animals (2.20.3). The best method is expensive in terms of manhours. White rightly says: "So long as there was a plentiful supply of labour there was no pressure to introduce labour-saving machinery" (*art. cit.*).

[108] *Art. cit.*, 40.

[109] Judging from his recent paper *Pline le Jeune et les problèmes économiques de son temps*, Rev. Ét. Anc. 69, 1967, 62 ff. I would not be surprised if this would be the main thesis of Prof. Martin. In this article Martin rightly contrasts the mentality of Pliny the Younger and Columella with that of the great majority of 1st century A.D. landowners. Pliny and Columella are convinced that viticulture pays well provided the landowner is interested in the subject, supervises the operation himself or else, preferably, leases the land to coloni and is prepared to invest money in the vineyard. However, his views on Pliny III, 19.4 and 7, in which he finds an awareness of the economic importance of investment, seem oversubtle. The 'pulchritudo iungendi' (III. 19.2) and the feeling that the new lands produce a 'reditum sicut modicum ita statum' seems more important than the meteorological point in

would not seriously affect our case. For Columella criticizes contemporary estate-owners so frequently and consistently that the conclusion obtrudes itself: Columella, for all his supposed sensitivity to economic activities (q.e.d.!), was a rather lonely man. Columella brilliantly describes the prevailing mentality of 1st century A.D. landowners "who for various reasons abandon their most beautifully planted vine-yards before they reach the age of bearing, some shrinking from the yearly expense and thinking it the first and surest income to have no outgo at all . . Some consider it a fine thing to have extensive rather than well-tended vine-yards. I have known a very great number also who were convinced that their land must be cultivated, whether by good means or bad". Pliny the Elder corroborates this description: "nothing can be less profitable than to cultivate your land to the fullest extent (optime)". He praises the ancestors whose highest wisdom was to spend as little as possible ('ut quam minimum esset impendii').[110] The significance of the

§ 4. Pliny's tendency to buy good slaves instead of chained ones (§ 7) must be accounted for on ethical rather than on economical grounds. Columella, supposedly Pliny's model, recommends the use of chained slaves in vine-yards. These slaves are both strong and quick-witted but also unruly and consequently they work in chains under the supervision of a '*monitor*'. Columella adds that an *honest* man (homo frugi) of equal quickwittedness will of course do everything as well as the unruly bad slaves. Pliny rejects the use of chained slaves and prefers to buy good honest slaves (frugi mancipia); for the latter he has to pay more; apparently unruly (and intelligent) slaves are cheaper than honest ones who are equally intelligent. Pliny's slaves cost more because they are more reliable. Pliny's criterion is ethical, not that of "un exploitant agricole". Instead of talking too quickly about an investment-mentality scholars would do better to ponder the views of the modern economist Schumpeter, as quoted by Finley, *art. cit.*, 40, 38; cf. also id. *The Ancient Economy* (London 1973), 202, note 51.

[110] Columella IV, 3. Pliny, *N.H.*, XVIII, 30, 36, 39, 43; on these passages cf. J. J. M. Taeymans, *De Naturalis Historia van C. Plinius Maior als bron voor de economische geschiedenis van de Romeinse Koningstijd en Republiek*, Leiden diss. 1962, 140-1. In general Pliny is convinced that a farmer, who wants to cultivate his land well, should be prepared to work as hard as possible: profecto operā, non impensā, cultura constat (indeed husbandry depends on labour, not on expenditure, bk. 18.43). The Loeb-text reads "profecto opera impensa cultura constat" (husbandry depends on expenditure of labour). The Teubner-text seems preferable here. Quite apart from the fact that most Mss read "non impensa", it may be said that Pliny himself tends to distinguish between operā (the farmer himself, his family or other people who are interested in agriculture) and impendium (slaves, wage-labourers and a fortiori expensive implements); the latter should be kept

saying 'nothing ventured, nothing gained' would have been entirely lost on landowners with this kind of outlook. These two passages show that the average landowner was not inclined to adopt better agricultural methods or to employ or purchase labour-saving devices that involved an initial outlay. It was simply considered not worthwile installing a watermill for mechanising and cutting down the work of grinding corn, as long as a grainmill, probably tariffed without its wheel, shaft and steering gear, costs 500, 750 or 1750 denarii more than a horse-mill, donkey-mill or handmill respectively.[111]

These passages relating to the mentality of the average landowner are the more important since throughout antiquity agriculture remained the basis of economic life. Finley and I myself have simultaneously and independently emphasized this point.[112] Naturally there were important centres of trade,[113] like Ostia and Alexandria, but in terms of the taxes paid by the various sectors of economic life commerce and business were relatively unimportant even in the big trading centres. Admittedly, in recent studies [114] on specific regions of the Roman Empire there is a tendency to emphasize the role of towns, bureaucracy and army as consumers of agricultural

down as much as possible. The case of C. Furius Cresimus illustrates the principle (18.41-2). The emphasis is on the zeal and devotion of the worker(s). Admittedly Furius had "ferramenta egregie facta" (iron tools of excellent make) such as "heavy mattocks, ponderous plough-shares and well-fed oxen"; however, the financial aspect of these high-quality implements is not considered at all by Pliny.

[111] Cf. L. A. Moritz, *Grainmills and Flour in Classical Antiquity*, 1958, 102 and 138; K. T. Erim-J. Reynolds, JRS 63, 1973, 102 and 107.

[112] Finley, *op. cit.*, 40/41; Pleket, *art. cit.*, 23; see now also M. I. Finley, *The Ancient Economy* (London 1973), 109 ff.

[113] As to the use of hoisting machinery for loading and unloading vessels in the harbour see now J. Rougé, *L'organisation du commerce maritime en Méditerranée sous l'Empire romain*, Paris 1966, 160 ff. After an analysis of the devices, described by Vitruvius, he concludes: "Ces engins furent réservés à des emplois bien déterminés et . . seule une petite partie des quais en était pourvus, celle où venaient aborder les marchandises pondéreuses et peu maniables" (165). In this area it seems particularly appropriate to say that the results achieved by means of hoisting machinery would have been unobtainable with manpower alone.

[114] *E.g.* those by L. Ruggini on the interaction between commerce and agriculture in the later Roman Empire (references and a short discussion in P. R. C. Brown, *The Later Roman Empire*, Econ. Hist. Review 1967, 327 ff., esp. 341/2 with note 4 on 341).

products and thus as factors promoting the growth of agriculture; and since these products have to be transported to the urban areas, trade is likely to have been stimulated by this process. But in many cases this will have been short-distance trade over land, long distance transport being prohibitively expensive; the only effect will have been that a number of people found a mode of existence in this branch; how large a number this was, we do not know; the phenomenon of the grower who markets his own products should not be underrated. The function of the towns in any pre-industrial, agrarian society is extremely hard to asses, let alone to quantify.[115] It is a truism but probably true that the cities (and especially the inland-cities which are superior in number) were fed by the countryside and in that sense constituted a market for the agrarian sector. But this is not tantamount to saying that the average inland-city as a consuming entity promoted or guaranteed the growth of agriculture. The whole concept of "economic growth" in a marginal agrarian society may well be misleading rather than illuminating. "Growth" may well have been merely a function of demographic expansion and may well have expressed itself in the enlargement of the cultivated area rather than in the improvement of the yield of that area or of the ratio between profit and investment. Often enough, though certainly not always and everywhere, the structure of landed property in the Roman Empire was such that the estate-owners (and not the small farmers) benefited from such "growth". Essential is what they did with their wealth; we shall come back to that further down.

Cities, which were centres of long-distance trade, are a different matter perhaps. The Campanian cities which up to the end of the first century A.D. functioned as centres of a flourishing wine-trade and which have been admirably described by Rostovtzeff, determined the prosperity of the Hinterland.[116] But is essential to note

[115] It seems worthy of note that in E. Le Roy-Ladurie's *Les paysans de Languedoc*, Paris 1968, the cities as a factor in the economic life of the pre-industrial, predominantly rural society of Languedoc are almost absent. This may well be due not so much to the inadvertence of Le Roy as to the fact that the role of the cities actually *was* of minor significance for a long time (cf. also L. Bergeron's valuable review in History and Theory 7, 1968, 367-377).

[116] According to Bergeron (see note 115) the "déblocage" of the immobile rural economy of Languedoc was brought about by the expansion of viti-

that the Roman government with the exception of a short-lived attempt of the 'bad' (!) emperor Domitian, did nothing to prevent the rise of a provincial viticulture, which conquered the local markets and thereby contributed to the decline of the Campanian wine-trade; and even in the heigh-days of that trade we meet Petronius' Trimalchio who quickly invested his profits from the wine-trade in as much land as he could get; his ideal was to be able to walk from Campania all the way to southern Italy on his own land. 'Gentleman' and 'landowner' were synonyms. Money made in commerce was quickly invested in land.

The question should be asked what the wealthy actually did do with their wealth acquired either in commerce (and subsequently invested in land) or in agriculture? A probable answer is that some was used for buying still more land,[117] some was hoarded, and some spent in benefactions to the population. The Benefactor—the euergetēs—is a central figure in ancient society. The euergetes-economy is basically a prestige-economy,[118] though it must be conceded that according to modern economic standards the numerous donations of the ancient euergetai can be regarded as 'investments'. By giving money for statues, public buildings, new pavements of the streets, etc. etc., the benefactor, presumably unintentionally, created employment for urban craftsmen.

culture, commerce and manufacture. The new city-bourgeois, whose mentality had changed with the introduction of a new educational system, seems to have played a predominant role in this process. Thank to the cities the rural world has been incorporated in a new economy in which products were exchanged over long-distances. The parallel with Campania obtrudes itself.

[117] Pliny, *Ep.* X. 54, 55 well illustrates the fact that the only conceivable "neg-otium" for "pecunia otiosa" was to add to one's estates by purchasing more land; cf. also Columella's words quoted above in the text: "Some consider it a fine thing to have *extensive* (italics are mine H.W.P.) rather than well-tended vineyards". For this and the following paragraphs I heavily draw on my article in Acta Historiae Neerlandica II, 1967, to which I refer the reader for more details. I have not repeated the references given there. For some fine remarks on "évergétisme" as a "way of life" in the pre-industrial ancient world see P. Veyne, *L'évergétisme devant les sciences humaines*, Annales 1969, 785 ff., esp. 806 f.

[118] In an attempt to describe the prevailing mentality of the landowning class in Languedoc L. Bergeron (*art. cit.*, (see note 115) 375) writes about the "consommation dans une mode de vie *ostentatoire* (italics are mine H.W.P.) aux multiples aspects", which precluded the use of capital for purposes of investment in order to raise the productivity in any branch of economic life.

However, benefactions were not 'investments' inasmuch as they did not promote (accelerate) the production of goods. Landowners did not consistently strive to step up the yield of their lands; they did not use the technological possibilities, though in the long run such may have cost less money than large groups of slaves and/or free labourers. These landed magnates were wealthy anyhow and they did not bother about using the most elaborate technical devices in order to become even wealthier. I am not preaching a sermon here and, accordingly, I do not censure this mentality. I am fully satisfied if this picture of the mentality of the upper strata of ancient society is acceptable and contributes to a better understanding of why technical innovation and economic progress in antiquity were two unconnected conceptions. The first, if available, did not lead to the second. In general it seems true that urban civilization was paid for by the peasants: agriculture footed the bill. Towns became prosperous because of the low standard of living of most of the rural population. These low standards in their turn explain why mass-production was virtually unknown in antiquity: the marketing prospects were hardly engaging! Ancient industry was basically a matter of one or more workshops where production could only be stepped up by increasing the number of workmen. Kiechle [119] has drawn attention to the fact that, where technical progress is recorded, it has been directed towards the production of luxury-items: hypocausts, glassware, Arezzean *terra sigillata* with relief-decorations. The "Befestigungsschraube" has been used mainly for the production of luxury metal-ware. For these things there was a market. The aristocratic upper-ten showed interest in and thereby encouraged the production of luxury-items. Although Seneca and Posidonius may have argued that the 'vitrearius' (glass-blower) was clear proof of the wickedness of technique,[120] the leading circles happily bought his products.

Incidentally, it has recently been suggested that, quite apart from the mentality of the upperclass and the economic infra-structure of society, the Ancients simply did not have the technical means to produce labour-saving implements: "Für die Dampfmaschine waren Rohre und Befestigungsschrauben aus Eisen nötig, die erst

[119] *Op. cit., passim.*

[120] See above p. 10 with note 20.

1600 Jahre später hergestellt werden konnten".[121] However, Kiechle has pointed out that the ancients did know the "Befestigungsschraube" but used it for other purposes. There is no point in denying the technical underdevelopment of the ancient world in certain branches but this is not so much a factor which can be used to explain the absence of labour-saving devices as a phenomenon which should be explained itself or at least correlated with other phenomena. Kiechle deserves to be quoted in full: "Und ebensowenig erscheint die Meinung stichhaltig, die Metallurgie sei im Altertum noch nicht so weit entwickelt gewesen um den Bau verwendungsfähiger Dampfmaschinen zu ermöglichen. Sofern dies wirklich zunächst noch der Fall war, hätte deren Erfindung geradezu einen Ansporn darstellen können die Metallurgie in dem erforderlichen Masse zu vervolkommen. Als im 14. Jh. dass Schiesspulver aufkam, war sie auch noch nicht weit genug entwickelt, um alsbald brauchbare Musketen und Kanonen liefern zu können. Aber binnen eines Jahrhunderts . . hatte sich die Metallverarbeitung ausreichend vervollkommet . .".[122]

In conclusion I would say that most technical advances made in antiquity were in the field of 'banausic' occupations, on the handicraft level and, in close connection with the latter, in the building-trade. R. J. Forbes, in his excellent contributions to the subject, has provided us with a mine of information on what was achieved in these fields. The insights gained by the ancients in natural science and mechanics were only applied in a fitful, halfhearted manner to the construction of labour-saving instruments. On the one hand it may be said that labour-saving devices such as the lever, pulley and waterwheel (sakiyeh) were certainly used, and in the field of war machinery in particular achieved results would have been quite unobtainable with manpower alone; but on the other hand we find a distinct attitude of disapproval towards the use of labour -replacing instruments (the watermill, reaping machine and cogged wheel) in the civil sector.

It is significant that, when the late Roman geometer Pappus of Alexandria inter alia advocates the great importance of theoretical

[121] A. G. Drachmann, *Grosse Griechische Erfinder*, 1967, 48 quoted and accepted by Lämmli, *op. cit.*, 142, note 327a.

[122] Kiechle, *op. cit.*, 154.

and practical mechanics and points out that this science deals not only with natural motions but also with those which are 'contrary to nature', the paragraph on practical applications focusses on craftmanship (in metal-working, carpentering, painting) and on building and not on a discussion of labour-saving machines in general and in agriculture in particular. The man who has been well trained both in theoretical and applied mechanics is 'the best inventor of mechanical devices and builder'; the mechanical devices obviously relate to the building trade. Anthemius, one of the builders of the St. Sophia, is known to have written a treatise "Concerning remarkable mechanical devices" (Περὶ παραδόξων μηχανημάτων): does not the context of Anthemius' main profession suggest that these were devices, used or to be used in the building trade? Such devices above all made it possible to achieve things which otherwise, h.e. with muscular power, would have been virtually impossible. They also served to erect great prestige-objects. Rational purposes of labour-saving were absent.[123] Since according to Pappus it is impossible to know all the theoretical and practical aspects of mechanics, one shall have to make one's choice. This leads up to a discussion of the *technai* which one could choose and which administer the needs of daily life. Building and the devices used for lifting heavy burdens again come first, followed by military and water-raising machines. The latter enable people to raise water from great depths with greater ease. The emphasis is on the ease with which a job could be done, not on labour-saving or cheapness; and agricultural 'machines' are fully absent. Significantly those who construct machines for lifting heavy burdens are called "magganarioi": μάγγανον means "trick", "sorcery"; we are in the realm of the *thaumata*![124]

In conclusion I may cite the following typical instance relating to the cogged wheel. The Romans certainly deserve praise for their achievements in land surveying, as is very clearly shown by the treatises on this subject that have come down to us, as well as by recent developments in aerial photography. Moreover, highway construction and the setting up of milestones made this 'ars' a necessity. The Alexandrian school of engineers had employed a

[123] Cf. note 54 above, with G. Downey, Byzantion 18 (1948), 106/7, 113.
[124] Cf. Fr. Krafft, *art. cit.* (see note 51), 6, with note 20.

complicated system of gearwheels as the transmission mechanism of a 'hodometer', i.e. a carriage that, as it moved, measured the distance traversed, and passed on, in a simple manner, the result to the coachman.[125] But Roman landsurveyors failed to make use of such a first-rate time- and laboursaving device. We are informed by a passage in the 'Historia Augusta' [126] that the emperor Commodus left a hodometer in his legacy. The reaction of Pertinax, the typically senatorial successor of Commodus, is highly significant; he speaks of carriages 'which measure the distance travelled and tell the time, and other articles that were designed for the indulgence of his vices'.[127] Is this one more example, as in the case of Dionysius of Sicily, of the despot's predilection for spectacular technological applications, one that was also the outcome of a conscious opposition to the cultural ideals of his environment? At any rate, Pertinax won the day with his opinion that the hodometer was to be classed as a 'vice' and was therefore to be condemned. The best-known landsurveyors of antiquity measured everything by hand, for the same reason that other labour-saving devices were nearly always prevented from getting beyond the research stage, or only passed it at a very late period.[128]

*Appendix*: *A technological Revolution in Roman Agriculture*?

J. Kolendo has recently argued in two stimulating and thought-provoking articles (*Le travail à bras et le progrès technique dans l'agriculture de l'Italie antique*, Acta Poloniae Historica 18, 1968,

[125] Cohen-Drabkin, *op. cit.*, 342 ff. (Hero of Alexandria). Vitruvius also describes this discovery, *De Architectura* X. 9.1-4, and even calls it 'non inutilem'.

[126] SHA, *Life of Pertinax* VIII. 6.

[127] '(vehicula) iter metientia horasque monstrantia et cetera vitiis eius convenientia'.

[128] It is very significant that the 'astronomical machine' fished up from the sea near Antikythera has a transmission system of 'gearwheels' (for the Antikythera discovery cf. E. Morpurgo: *De Astronomische Rekenmachine van de Grieken*, Hermeneus 35, 1964, 213 ff.; 226 ff. (with bibliographical references)). Drachmann, *op. cit.*, 32 rightly observes that except in watermills and in the Antikythera instrument we nowhere find gearwheels used in practice. Nor was the Antikythera instrument a universally employed labour -saver, and we have seen how much time and trouble were needed before the watermill found a certain acceptance. But in the end it achieved a minor victory that was altogether denied to the hodometer.

51-62; *Avènement et propagation de la herse en Italie antique*, Archeologia 22, 1971, 104 ff.) that a kind of a 'technical revolution' took place in Roman agriculture between 100 B.C. and 100 A.D.: in this period human labour is said to have been replaced to a considerable extent by animal traction. According to K. the introduction of the harrow (la herse; cratis) is of crucial importance here: "La herse élimina l'emploi de la houe pour l'émottement de la terre après le labourage et pour le recouvrement du grain". I have the impression that on the basis of the evidence submitted by him in his articles his thesis on the technical revolution in Roman agriculture, necessitated by an increasing shortage of slaves in the early Empire, is perhaps not entirely convincing.

The crucial point seems to me to be the following: there is admittedly evidence to show that the harrow (cratis) was used in Italian agriculture but there is no convincing evidence to warrant the conclusion that its use was general and widespread to the extent that it eliminated "l'emploi de la houe" and thereby replaced human labour. The breaking of the clods after the first ploughing is a labour-consuming job. The ancient agronomists were aware of that. Varro, Columella and Pliny all recommend repeated ploughing. This would either make the 'occatio' (breaking of clods after ploughing) almost superfluous or reduce it to an absolute minimum. Pliny (18, 180) says that, if necessary, the *occatio* should be done *crate vel rastro* (with a framework or a rake). Similarly Vergil (Georgica, I, 94) writes about the small farmer who breaks the clods *inertis rastris* and draws bush-harrows. Varro (I, 29) also recommends a second ploughing in order to break the clods (offringere glaebas; cf. 1, 32). After the sowing the farmer should plough a third time with a special ploughshare in order to cover the seed in ridges. Varro specifically adds that on farms which were not very large, any large clods, left on the ridges, were broken up with hoes. The implication seems to be that on large estates no hoeing was done. Varro's report does not entitle us to say that *the* small farmers in Italy used manpower for the breaking up of the clods. Varro is only concerned with the (presence of) clods (if any) on ridges, which were made with a special plough after the sowing. The use of an animal-drawn harrow was simply out of the question here, because it would have levelled the field and destroyed the ridges. However, in I, 31 Varro deals with

the digging or ploughing of new vineyards: this operation should be followed by the *occatio*: *occare, id est comminuere, ne sit glaeba. Quod ita occidunt, occare dictum.* This sentence suggests—*'they crush* the ground'—that Varro refers to human labour. In fact the very wording (*vineas novellas fodere aut arare*) strongly suggests that in general the author was not interested in the problem of saving of manpower.[129]

So far we have noticed that the harrow was a known implement but that its use was not specifically recommended by the agronomists on the basis of its labour-saving effect. Pliny's *vel* (*crate vel rastro*) hardly betrays any excitement at all. A technical revolution in Roman agriculture is hardly compatible with such a lukewarm attitude. Vergil's wording suggests to me that the peasant himself (and *not* animal force) may have drawn the harrow. If that is true, the labour-saving aspect surely becomes less dominant. Moreover I am not convinced that the *cratis viminea* is used by Vergil's peasant for the breaking up of the clods. The latter seems to be done

[129] Cf. for a similar indifference Columella II. 2.13: *quae vel aratro fieri potest* (n.b. vel!). Remarkably enough in the preceding paragraph 12 Columella mentions the *vilitas operarum* (cheapness of labour) as an essential factor. However, the problem there is how to handle the stones in a particularly stony field: one either gathers up the stones and piles them up on parts of the field or one will have to bury them in a deep-dug trench. The latter is only to be recommended if labour is cheap. In his chapters on the planting of vines (III. 13.3-4) Columella points out that the distance between the rows depends on whether the man who cultivates the vines wants to use the oxen and plough or the mattock: *vel aratro vel bidente.* Again he is clearly not affected by the problem of labour -costs. Those farmers who set their vines at such intervals that the ground may be broken up by diagonal and cross ploughing, are certainly not praised by Columella for bringing down labour-costs. In fact they are hardly praised at all: "This sort of vineyard is not to the advantage of the farmer, except where, in very fertile soil, the vine is of large growth". In IV. 4.2-3 and IV. 5 he advocates the loosening of the trenched ground of the vineyard by frequent digging (*crebris fossionibus*). The digging is supposed to pulverize the soil. The *aratrum* is not even mentioned. He also points out that the number of times that the ground should be turned by the hoes (*bidentibus*) should be limitless, since it is agreed that the more frequent it is, the more beneficial is the digging. At this point Columella again becomes aware of the problem of labour -costs (for that is what *impensae* possibly means here) and propounds a compromise: once a month a *"fossio"* (from March to October) will do. The awareness of the problem of expenses does not lead to the rejection of the mattock in favour of the plough.

with the hoe; the *cratis* may well have levelled off the field.[130] Actually Columella explicitly tells us (II. 17.4) that a thoroughly ploughed and hoed piece of land should be levelled by drawing a brushwood drag over it (*inducta crate coaequabimus*). This is the only place where Columella (a contemporary of Pliny the Elder!) mentions the *cratis* at all. Like all other agronomists he strongly emphasizes the importance of repeated ploughing (II. 4, 1-2) as a means of avoiding the *occatio*, but when in II. 17, 3-4 he comes to talk about the establishing of new meadows he writes that in the third year, after a thorough ploughing and after the sowing of vetch mixed with hay-seed, the clods must be broken *with hoes* (*glaebas sarculis resolvemus*). In several other passages (II. 10, 5; II. 10, 26) II. 12, 1 ff.) the use of the plain verb *occare* (or the noun *occator*) does not help a great deal to answer the question whether animal-drawn harrows or hoes were used.

Even if it could be shown (*quod non*) that the evidence from Pliny is unequivocal in stressing the unique importance and the labour-saving function of the animal-drawn harrow (*cratis*), we would have to face the fact that his contemporary Columella seems hardly aware of this 'technological revolution' in Roman agriculture. Columella (see p. 33) surely is interested in efficiency but in his own peculiar way. Labour -saving implements did not have his interest.

Human labour also played an important role in another agricultural operation: the covering of the broadcast seed. As Kolendo points out, the Romans used several methods. They threw the seed in the furrows (*sulci*) and covered it with earth (Columella II. 4, 11 at the end). The latter was done with the hoe. The second method was to sow in ground, that was well prepared and levelled in advance, and subsequently to cover the seed in ridges with *tabula(e)* (board(s)) attached to the ploughshare (Varro 1. 29, 2; Columella II. 4, 8; Pliny XVIII, § 180). A third method was to plough a field with a heavy plough, as described by Pliny 18, 172,[131] to throw the

[130] See in the same sense K. D. White, *op. cit.* (see note 88), 147.

[131] Pliny, *N.H.*, 18.172: "latior haec quarto generi et acutior in mucronem fastigata eodemque gladio scindens solum et acie laterum radices herbarum secans; non pridem inventum in Raetia Galliae duas addere tali rotulas (or: ut duas adderent tali) quod genus vocant plaumorati; cuspis effigiem palae habet. serunt ita non nisi culta terra et fere nova; latitudo vomeris caespites

seed in the furrows and to draw toothed harrows (*crates dentatas*) over the furrows so as to break the clods and to cover the broadcast seed.

Kolendo is right in asserting that not the use of the toothed harrow but the addition of two wheels to the heavy plough was a recent invention, made by the farmers of Raetia Gallia. However, the plough which Pliny mentions in connection with the toothed harrow, is just one out of a series of four, which he all describes. This heavy plough, equipped with a special blade, was to be used only in *culta terra et fere nova*. These two restrictions (ploughs of various patterns; geography) do not seem to support Kolendo's conclusion that "l'emploi de la herse était, selon Pline, *très répandu* (italics are mine, H.W.P.)". The use of the *cratis dentata* was a possibility, not a generally accepted and applied method. Pliny's contemporary Columella does not mention the *cratis* in this connection. As said before, he once mentions the *cratis* (presumably the brushwood harrow) as an implement which was used only for levelling the surface of a ploughed field.[132]

versat, semen protinus iniciunt cratesque dentatas supertrahunt. nec sarienda sunt hoc modo sata, sed protelis binis ternisque sic arant".

[132] In *N.H.* 18.180 Pliny again mentions the *cratis*. Since the context is important, I give the whole passage: "Aratione per traversum iterata occatio sequitur, ubi res poscit, crate vel rastro, et sato semine iteratur haec quoque, ubi consultudo patitur, crate contenta vel tabula aratro adnexa — quod vocant lirare — operiente semina". The first part of the sentence has been discussed in the text (p. 42); the final part of the sentence deals with operations after the seed has been sown. "Haec quoque" would seem to refer to the *occatio* which here follows upon the sowing. Now, as Kolendo points out, *occatio* has two meanings: "L'émottement de la terre après la labourage"; "Le recouvrement des emblavures". The function of the tabula, attached to the plough, is precisely to cover the broadcast seed in ridges. This method is used when the seed had been thrown in a field which had been levelled off before ("Cet instrument servit à enfouir la semence jetée auparavant sur la surface nivelée du champ", Kolendo, *art. cit.*, 55). The *cratis contenta* seems to have been used for the same purpose, *viz.* the covering of the seed; it is a "well tightened brushwood harrow". It was not supposed to break heavy clods—that operation belonged already to the past and had been described in the first part of the sentence—but to cover the seed and presumably to level the field. K. D. White, *op. cit.*, 149, however, reads *crate dentata*, unfortunately without any discussion of the textual problems; *dentata* is an emendation of the mss-reading *contenta* (cf. the apparatus criticus of C. Mayhoff's Teubner-edition, vol. III, 192). White translates: "this second ploughing is also repeated after the seed has been sown, by means of a toothed harrow (*crate dentata*) . ." (*Agricultural Implements of the Roman*

There is another point: Pliny emphasizes the fact that the heavy plough was drawn by teams of two or three pairs of oxen. Columella is also in favour of working the land deep (II, 4.23 ff.) but he realizes that certain farmers, led by Cornelius Celsus, "shrunk from the expense which is undoubtedly greater in the case of larger cattle" and "used small ploughs, which could be operated with oxen of smaller size". Celsus seems to represent a rather large number of estate-owners (IV, 3, 3) whose primary concern was to cut down expenses, whereas Columella emphatically asserts that large investments, followed by careful working of the ground and careful handling of the crops, would give a good return. Incidentally, scholars suggested [133] that the heavy plough from the North could not have been used in Mediterranean agriculture because the sun would have burnt the moist out of the clods. Against this it may be said that Pliny for one restricts the use of this plough to "culta terra et fere nova". Such "terra" was no more and no less available in the Mediterranean than in the North. Furthermore Columella's above mentioned description of the mentality of Cornelius Celsus cum suis shows that to Celsus' mind it was only the size and the number of oxen (and not climatological considerations!) that militated against the use of the heavy plough. Finally, the argument about the desiccating of the soil looses some of its weight, when we assume that, in view of the habit of sowing in the autumn, most of the ploughing will have been done in the late summer or early autumn (and not in the hot summer or late, but still relatively hot, spring).

All this tempts me to draw the conclusion that many farmers in spite of Columella's warnings, certainly did not work with the type of plough, as described by Pliny (18, 172), and consequently that the heavy toothed harrow, which apparently was used in close connection with the heavy plough, was by no means a common and

*World*, Cambridge 1967, 149). He compares this passage with 18.172 (see note 131 above). However, in 18.172 a heavy iron harrow is appropriate enough. After the ploughing the harrow is supposed to break the heavy clods and to cover the seed (= tantamount to levelling off the ground). In 18.180 there is no need for a *cratis dentata*. Moreover *contenta* seems also preferable on the basis of the time-honoured dictum "lectio difficilior potior".

[133] Cf. J. L. Teall, *The Grain Supply of the Byzantine Empire*, 330-1025, Dumbarton Oaks Papers 13, 1959, 89 ff., esp. 129 (with further references).

wide-spread implement.[134] One further passage from Columella may perhaps illustrate my point. In II, 10, 26 he advises the peasant on how to plant Medic clover (lucern). After repeated ploughing and hoeing and manuring the seed is to be sown at the end of April: "When you have done so, the seed should be covered at once with *wooden rakes* (ligneis rastris) . . . After the seed is sown the place should not be touched with iron; and so, as I have said, it must be hoed with wooden implements and repeatedly freed of weeds". The supposed allergy of Medic for iron cannot have prevented the farmers from using a *cratis viminea* for the purpose of levelling the field and covering the seed. Why, then, does Columella not mention this possibility? Presumably because the use of harrows (both the heavy toothed harrow, designed to effect the double task of breaking up the clods and levelling off the field and the light brushwood harrow which reduces the surface to a fine tilth and covers the seed with a thin layer of loose earth) was not as common and widespread as Kolendo assumes? [135]

[134] K. D. White (*op. cit.*, 149) infers from 18.180 (but cf. note 132) "that the use of the heavy animal-drawn harrow enabled the farmer, where local custom allowed, to cut down on the exhausting labour of repeatedly ploughing the fallow". It may be that Pliny himself found the saving of labour so obvious that he did not mention it explicitly as the decisive motive for using this method; whatever his personal feeling may have been, the restrictive clause *ubi consuetudo patitur* should not be forgotten nor should we forget that his contemporary Columella frequently emphasizes the importance of repeated ploughing. Apparently it did not occur to him (or it did not interest him!) that the labour could be cut down by applying the method described by Pliny. The existence of a certain technique does not imply its *wide-spread* use. If ever, modern parallels from the era of our 'technological revolution' are risky here.

[135] The suggestion of G. E. Fussell-A. Kenny, *art. cit.* (see note 23 above), 206, that Cato's four *crates stercorariae* (*De Agric.* 10, 2) were harrows, used to 'plough manure' in the ground, is ingenious but perhaps improbable. The large number induced the authors to suppose that it were very light brushwood-harrows, drawn by human force, and used at the same as transport-boards for the manure. They use the *crates dentatae* from Pliny 18.172 as a parallel. However, Pliny does not say that the toothed harrows were used in order to 'plough' manure into the ground; moreover, even if it were possible to use Pliny's heavy harrows for this purpose, this does by no means imply that Cato's supposed light-weight harrows (which were só light, that the peasants themselves could draw them) could have done the same job. Consequently I feel that '*cratis* = basket' is a safer interpretation here.