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AN URBAN AGRO-ECOSYSTEM: THE EXAMPLE OF NINETEENTH-CENTURY PARIS

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ABSTRACT

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One hundred years ago a sixth of the area of Paris was used to produce annually more than 100,000 tons of high-value, out-of-season, salad crops. This cropping system was sustained by the use of approximately one million tons of stable manure produced each year by the horses which provided the power for the city's transport system. Sufficient surplus "soil" was produced to expand the production area by 6% yr^{-1}. In energy, mass and monetary terms the inputs and outputs of the Parisian urban agro-ecosystem exceed those of most examples of present-day, fully industrialized crop production. The productive biological recycling of the waste products of the city's transport system contrasts favourably with the requirements and consequences of the simplified, present-day urban ecosystem.

INTRODUCTION

The acquisition, processing and distribution of food and the disposal of its end-products are major factors in determining the energy consumption and pollution production by the large urban centres of the industrialized world, processes which are having an increasingly important effect on agricultural and other nonurban ecosystems.

In previous centuries, food production within urban centres was commonly of importance. Primary vegetable and fruit production provided a valuable addition of fresh food to the diet, reduced transport and storage problems, increased the limited green area for gas exchange within the city, and provided an important sink for animal wastes. By contrast, secondary animal production of milk, meat and eggs within cities tended to compound their transport and pollution problems through the large volume of animal feed needed and the almost equal volume of waste produced. The latter and the animals themselves also caused health hazards to the human population.

This paper presents a quantitative description, and attempts an approximate energy and mass flow analysis, of one outstanding urban agro-ecosystem — the "marais" of Paris, during the second half of the nineteenth century — the period of its maximum importance.

The marais system of cultivation appears to have been one of the most productive ever documented. In addition to providing a significant proportion of the city's fresh food, it supplied a valuable export market and transformed the major transport pollution problem of the time into an asset by turning vast quantities of stable manure into a surplus of highly fertile soil.

Following descriptions by Kropotkin (1899) and Smith (1911), the system became known in the English-reading world under the name of "French gardening". However, most of the later accounts in English are derivative, unquantitative, and contain exaggerated claims.

In view of the worldwide spread of urbanization with its attendant problems, it was thought that a quantitative description and analysis of the solution, albeit partial and temporary, provided by the "maraîchers" of Paris one hundred years ago, might still be of interest.

DATA SOURCES

The more detailed descriptions of the system are naturally in French, and a list of the most useful sources is given in Table I. Particular use was made of the first two books listed, which are complementary in that the description by Courtois-Gerard (1858) provides a detailed survey of the system as a

TABLE I

Source material on the Paris marais culture and French gardening

In French

1. Manuel pratique de culture maraichère. Courtois-Gerard, 1858. A detailed survey of entire system.
2. La culture maraichère pratique des environs de Paris. Ponce, 1869. An account of the author's holding.
3. Marais. Larousse, 1865. p. 1118. A brief survey.
4. Les Maraîchers de Paris. Borie, 1856. A statistical account.
5. La question maraichère dans Paris et sa banlieu. Anon., 1887. Brief statistical summary.
6. Le maraîcher de Paris. Heuzé, 1897. Historical account.

In English

7. A quarter acre of French garden. Chapter 14 in Smith, 1911. A detailed description and budget based on results in England.
8. French gardening or intensive cultivation. Section 34 in Weather, 1913. Description of cultural methods and brief survey of returns in England.
9. Fields, Factories and Workshops. Kropotkin, 1899. Brief and popular account emphasizing productivity.
10. Crop production in frames and cloches. Bull. No. 65. Br. Min. Agric. Fish. Anon., 1932. Full description of cultural methods recommended for English conditions.
11. French gardening. Chapter 7 in Quarrell, 1938. Brief history of system in England with illustrated description of cultural methods.

whole, and that of Ponce (1869) contains a detailed description of his own holding. A recent, but brief account of the system as now practised in France is given by Anon. (1962).

The English-language sources listed in Table I include Smith's account (1911) based on results obtained in England where he helped introduce the system, a later authoritative description of the method as recommended for English conditions (Anon., 1932), and an illustrated textbook account by Quarrell (1938).

GENERAL DESCRIPTION AND HISTORY

The year-round production of high-quality salad and vegetable crops which characterized French gardening was based on inter- and successional cropping, in which as many as six and seldom less than three crops per year were harvested from each plot of land. Winter crop production was made possible, and growth rates were enhanced during the spring and autumn, by the heat and perhaps CO_2 released during the fermentation of stable manure. Additional heat was provided by glass-covered frames and bell-shaped glass cloches; by straw mats during severe weather and by the additional shelter from the 2-m-high walls which surrounded each smallholding. Frequent light irrigations were applied, adding to the high labour requirements.

The system of cultivation developed slowly from the walled gardens of medieval Paris, and reached its maximum sophistication and importance during the second half of the nineteenth century. A very brief historical account was given by Heuzé (1897) and a more detailed one by Courtois-Gerard (1858). The very rapid decline in the first quarter of the current century can be explained by three factors: the virtual replacement of the horse by the motor car, competition for land within the city, and competition from areas with more favourable climates outside the city — facilitated by improvements in the transport system.

The total area and number of holdings and persons engaged in the marais of Paris during this period are given in Table II, which lists also the sources

TABLE II

Statistics of Parisian marais during second half of the nineteenth century

Year	Total area (ha)	No. of holdings	No, of persons engaged	Average per holding		Source (see Table I)
				Size (ha)	Persons	
1844	593	1125	5205	0.53	4.6	1
1856	(1350)	1800	9000	0.75	5.0	4
1865	1400	1800	8500	0.78	4.7	3
1887	1378	1800	7500	0.77	4.2	5
1889	850		5000			9

used. The data suggest that the area reached a maximum of 1400 ha during the third quarter of the last century. At that time the average size of an individual holding was 0.7 ha, employing 4.5 persons. This latter figure agrees with that given by Ponce (1869) for his own holding and also is the average for the two French gardens in England described by Smith (1911) and Weather (1913).

During this same 25-year period, the population of Paris doubled from one to two million, although the total area within the city limits remained constant at 7800 ha.

MASS AND ENERGY INPUTS AND OUTPUTS

Most accounts of the system are in monetary terms, but sufficient detail appears in a number of the references given in Table I to allow approximate mass and energy balances to be constructed.

Although generally there is a close agreement between the values given by the different sources, no estimate of their accuracy was available. Hence the values presented should be regarded as best estimates of unknown accuracy.

INPUTS

The gross energy requirement or energy input of any production system depends critically on the boundary adopted for the system and this is of especial importance when considering labour-intensive systems (IFIAS, 1974; Leach, 1975). The convention adopted in this study was to include the land within the system, but to exclude the workers — apart from their energy input during work. The preceding two references outline the nomenclature, units and procedures followed herein.

Human labour

An average of 6.5 persons, including the owner and his family, were employed per hectare marais according to the five sources listed in Table II. On the basis of the information given in references 1, 2, 3 and 6 (Table I), it was estimated that one and a half persons per hectare were engaged in transporting produce to the market and manure to the holding. One-third of the labour force was female. Similar labour requirements have been given for the marais system as currently practised (Anon., 1962).

The human energy input into cultivation, which included moving by hand approximately 12,000 t ha^{-1} yr^{-1} of soil, manure and produce, was estimated at 24.00 GJ ha^{-1} yr^{-1} *. This figure was based on a labour input of 1 MJ hr^{-1} **, taken from Leach's (1975) value for vegetable cultivation in U.K. allotment

* GJ = gigajoule or 10^9 J = 238,894 Kcal
**MJ = megajoule or 10^6 J.

gardens, and a year of 300 working days, each of which averaged 16 hours (Courtois-Gerard, 1858).

The human energy input into transporting produce from and manure to the holding was estimated at 3.60 GJ ha^{-1} yr^{-1}, assuming a lower rate of energy input (0.66 MJ h^{-1}) and a shorter working day (12 hours) appropriate to the nature of the work (Ponce, 1869).

It should be noted that, by convention (IFIAS, 1974), the values given for the human energy input do not include support energy, i.e. that energy used for nonwork activities.

Animal labour

The average of figures from three references (1, 3 and 4 of Table I) indicates that one horse was kept to transport produce from and manure to the holding for each 0.91 ha of marais cultivated. The energy input in its feed was 68.250 GJ ha^{-1} yr^{-1}, based on 170 MJ per day for each animal (Morrison, 1949). The support energy includes amortization of the horse, its harness, cart and stable, and shoeing and veterinary attention. The energy inputs into these terms were, for lack of any practical alternative, assumed proportional to their monetary costs. Three references (Courtois-Gerard, 1858; Ponce, 1869; Brody, 1945) suggest these terms to total 27 ± 2% of the food cost and 5% was added to this mean value to allow for the energy cost of transporting fodder. The energy content of manure produced on the holding, estimated at 35.151 GJ ha^{-1} yr^{-1}, was subtracted from the total. This estimate was based on a stable manure production of 6 t per horse per year (Morrison, 1949; Anon., 1967), with a heat of combustion of 5.326 GJ t^{-1} calculated from the composition of fodder and bedding (Brody, 1945; Morrison, 1949) and of hotbeds constructed from stable manure (Tschierpe and Sinden, 1962).

The net energy requirement for animal labour was taken as half the support energy of the horse (see following section for details of partitioning), and with this term the gross energy requirement for animal labour was estimated to be 27.465 GJ ha^{-1} yr^{-1}.

Organic manure

Very heavy dressings of stable manure were an essential feature of the marais system, providing the fermenting "hotbeds" on which out-of-season crops were produced under glass protection. Rates of application reported range from 1060 t ha^{-1} yr^{-1} for very intensive holdings (with half of their area under glass) to 340 t ha^{-1} yr^{-1} for more extensive holdings without glass (Courtois-Gerard, 1858). As the average fraction covered by glass was one-quarter (see later), this suggests an average application of 702 t ha^{-1} yr^{-1}. The average of six other application rates taken from references 2, 4, 5, 7, 8 and 11 of Table I was 670 t ha^{-1} yr^{-1}, with an indication of reduction in later years. All the data together suggest a mean application rate of 675 t ha^{-1} yr^{-1}, and this figure was used in subsequent calculations. It represents the output of 112 horses.

The energy input in the stable manure was 3596 GJ ha^{-1} yr^{-1}. The value of support energy needed to produce the manure depends critically on the convention adopted to partiti on the horses' gross energy requirement between its two outputs, work and manure. Adopting the IFIAS (1974) recommendation to base partitioning on objective, physical parameters led to allocating half the gross energy requirement to manure production, as in energy terms the work performed equals that contained in the stable manure, each representing 20% of gross energy input (Brody, 1945; Morrison, 1949).

On this assumption, the support energy for manure production was estimated to be 2920 GJ ha^{-1} yr^{-1}.

The gross energy requirement for stable manure used to heat, fertilize and improve the physical characteristics of the marais totals 6516 GJ ha^{-1} yr^{-1}. This figure does not include the human and animal work inputs in transporting and handling the material, as these were included in the labour inputs. The importance of the partitioning convention is illustrated by the fact that the total gross energy requirement would be reduced by one-third if the support energy was allocated on the basis of the monetary cost of work and manure production, and probably even more if the price of the two outputs was used as the criterion.

Glass protection

Courtois-Gerard's (1858) survey of the Paris marais showed one-quarter of the cultivated area was covered by glass: 84 percent by frames and 16 percent by bell-shaped cloches. The average of the figures calculated from four other sources (refs. 2, 4, 7 and 8 of Table I) was identical.

The annual glass replacement requirement was calculated to be 175 m^2 ha^{-1} on the basis of contemporary descriptions of the dimensions of the frames and the cloches, together with the 5.8% yr^{-1} amortization rates averaged from refs. 1 and 2 of Table I. In addition, 2 m^3 of timber per hectare was needed annually to replace the wooden frames and their supports. The gross energy requirement of glass production was estimated at 166 MJ m^{-2}, half of the current value given by Chapman and Mortimer (1975); for wood the enthalpy value was used, 18.3 GJ t^{-1}.

Excluding labour terms included elsewhere, the gross energy requirement to maintain glass protection was estimated to total 49.0 GJ ha^{-1} yr^{-1}.

Straw mats

These were used to provide additional protection during very severe weather and had an average lifetime of only 2.5 years (Courtois-Gerard, 1858). The same source states that 200 m^3 ha^{-1} of straw was needed for the mats. These values, with estimates of density (0.017) and heat of combustion (18.4 GJ t^{-1}), give a gross energy content of the mats of 25.02 GJ ha^{-1} yr^{-1}. To this 6.60 GJ ha^{-1} yr^{-1} was added as half of the support energy for growing the wheat crop yielding the straw (Leach, 1975), the basis of partitioning the support energy being the equal energy yields of straw and grain. The estimated gross energy requirement for straw mat production totalled 31.62 GJ ha^{-1} yr^{-1}.

Miscellaneous

Included are seeds, fuel to operate the water pump, soot and naphtha applied in small quantities as pest deterrents, packing material, and the depreciation of hand tools and the irrigation system. The monetary cost of these terms was 6% of the annual running budget (Ponce, 1869); their gross energy requirement was taken as 10% of the total.

OUTPUTS

Crop production

Yields of the ten to twenty different salad, vegetable and fruit crops cultivated are available from three sources (Table III), the first of which presents estimates for a typical small, very intensive, glass-protected holding and also for a larger, less intensively cultivated marais.

In a number of cases yields were presented in numbers and the conversion to weight was based, whenever possible, on contemporary accounts of marketing practice. A check on this procedure was possible in the case of Ponce's 1.1-ha holding. Kropotkin's (1899) value for the fresh weight of produce

TABLE III

Statistics of crop production from Parisian marais during second half of the nineteenth century. All values are per hectare per year

Year	Fresh weight (t)	Dry weight (t)	Gross energy content (GJ)	Monetary return (francs)	Source (see Table I)
1858	78.74	6.21	55.778	24,980 (Intensive)	1
	78.20	6.73	60.172	11,579 (Extensive)	1
1856				10,000	4
1869	93.22	6.99	70.471		2
1872				10,000	3
1887				8,700	5
1911 England	74.8	4.94	43.817		7

marketed from this holding (103.3 t ha^{-1} yr^{-1}) was 10% above the figure estimated in this study.

Crop fresh weights were converted to both dry matter and gross energy content, using separate factors for each crop (Chatfield, 1954). These showed only small variations, the average dry matter content of all the crops being 7.6% and the average energy content 0.700 GJ t^{-1}, both on a fresh-weight basis.

The four estimates of total productivity are given in Table III. Mean values after averaging the first two estimates are 82.16 t fresh weight, 6.13 t dry matter and 1.07 t protein, all per unit hectare per year. The estimate of protein production was based on an average concentration of 0.013 fresh weight for the mixture of crops grown, taken from the data tabulated by Watt and Merrill (1963). The gross energy content of the crops marketed was 57.42 GJ ha^{-1} yr^{-1}.

It should be emphasized that all the productivity values given above refer to marketable produce and therefore represent an underestimate of total production.

Three further estimates of the marketed crops produced by the Parisian marais system as a whole are available in monetary terms and are presented on a unit area basis in Table III. The values indicate a decline in returns during the second half of the century but the data are insufficient to indicate if this represents a decline in real productivity.

Soil

The heavy dressings of stable manure applied year after year, equivalent to an average annual application approximately 30 cm deep over the entire holding, necessitated the regular disposal of surplus growing media. This material, predominantly spent hotbeds, was known as "terreau" and was used in part to expand the marais area. Courtois-Gerard (1858) states that the receipts from the sales of terreau covered one-seventh of the cost of purchasing fresh manure; a later reference (Anon., 1887) puts the fraction at one-quarter.

Ponce (1869) states that his holding disposed of 182 m^{-3} ha^{-1} yr^{-1} and this figure has been used to make a very approximate estimate of the gross energy content based on Morrison's (1949) values for the original composition of, and Tschierpe and Sinden's (1962) decay rates for, stable manure. The gross energy content so calculated was 1800 GJ ha^{-1} yr^{-1}.

Assuming that a 30-cm depth of growing media is sufficient, the volume of terreau produced each year should allow an annual expansion of 6% in the area of marais.

Productivity and efficiency of the Parisian marais

Judged by the criteria of marketable food, production of dry matter and metabolic energy or financial returns, the productivity of the marais system per unit area of land was extremely high.

The food marketed from each hectare could supply 15 persons with their caloric requirements (at 2400 Kcal per capita per day) and 54 persons with their proteins (at 54 g per capita per day). This human carrying capacity, admittedly on an extreme vegetarian diet, is equal to that of the most productive of current agricultural cropping systems (Leach, 1975). In terms of dry matter output, the production of the marais system one hundred years ago equalled that of all but the highest-yielding sugar and cereal crops grown today (Leach, 1975).

The maraîchers were interested primarily in maximizing the financial returns and to this end their cropping system concentrated on high-value, out-of-season winter crops and neglected the higher-yielding but lower-value summer crops. No doubt this emphasis reduced the total volume of production per year below the potential.

The gross annual monetary returns per hectare were approximately 10,000 fr (Table III). The buying power that this represented can be seen by noting that the annual wage of a marais worker, including food consumed on the holding, was less than 750 fr; the price of one hectare of marais was between 30,000 and 50,000 fr, and the annual rent per hectare varied between 1,000 and 1,700 fr (Courtois-Gerard, 1858).

The efficiency of the marais culture in converting the flux density of incident solar radiation to that of metabolic human food energy was 0.16%, or 0.32% if the photosynthetically active waveband is considered. This figure compares well with most agricultural systems; in deriving it the average annual insolation at Paris, 4.019 GJ m^{-2} yr^{-1} (Wallen, 1970), was reduced by 10% to allow for an estimated 40% loss of radiation by absorption and reflection from the glass-protected fraction of the holding.

Measured monetarily, the efficiency of the marais system was high. Using the balance sheets presented by Courtois-Gerard (1858), the annual profit of the typical marais at that time returned 15% of the capital investment, including in this latter term the average price of the land — 40,000 fr per hectare. For rented land — the more usual case — the annual profit, including the cost of the rent, returned 58% on the working capital required. It should be noted that the expenses do not include any wages for the proprietor or his family, but do include the cost of their food and habitation.

From the point of view of labour the efficiency of the marais system was extremely low. For the average holding, 2.34 MJ of metabolic food energy was produced on the holding per man-hour and 1.84 MJ hr^{-1} delivered at the market. These values are one order of magnitude below those quoted by Leach (1975) for a variety of preindustrial cropping systems and are three orders of magnitude below those of fully industrialized cropping systems as practised in the U.S.A. and the U.K. today.

The very high labour requirements of the marais system can in part be attributed to the emphasis on out-of-season cropping, requiring hotbed preparation and almost continuous attention to the ventilation and irrigation of the glass-protected crops. However, even for unprotected cropping, the improvement in output per man-hour is only one-third.

The efficiency of the marais in energy terms is also low. Using the average energy inputs and outputs presented in Table IV, the ratio of food energy produced to that used in its production is 0.25, i.e. four units of input were needed for each unit of metabolic food energy produced. In calculating this ratio the minor energy inputs into transport outside the holding were excluded and the remaining inputs were partitioned between food and terreau production in proportion to the ratio of their energy contents. A very similar energy output—input ratio, 0.23, was calculated for the less intensive marais without glass or hotbeds. This was so because, although the energy input was reduced by two-thirds, the energy output in terreau was proportionately reduced, causing a marked increase in the proportion of remaining energy inputs attributable to food production.

TABLE IV

Energy balance for average Parisian marais during second half of the nineteenth century (in GJ ha^{-1} yr^{-1}).

Output		Input	
Crops	57	Labour	28
Terreau	1800	Animal transport	28
		Stable manure	6516
		Glass maintenance	49
		Straw mats	32
		Miscellaneous (seeds, tools, etc.)	665
	1857		7318
of which: transport outside holding			31
: for 25% area under glass protection			4643

The energy balance of the marais system has been compared with the broad range of agricultural cropping systems in Fig.1. Both the yield and inputs exceed those of the current, fully industrialized cropping systems whose energy budgets were presented by Leach (1975). Data from the 41 cropping systems described by him were used to delimit the three classes of production: pre-, semi- and fully industrial cropping. Animal production systems were excluded; their human food yield, in energetic terms, was typically one order of magnitude less than that of food cropping systems operating at the same energy input level.

The energetic significance of the marais system does not lie so much in the high absolute levels of output and input, but rather in the fact that the energy input was primarily of biological origin, representing a renewable resource. In marked contrast, current fully industrialized food production systems of comparable flux densities are based on energy inputs either directly or indirectly, dependent on nonrenewable, fossil fuel sources.

Three high-energy and labour-intensive systems can be directly compared with the marais. Currently U.K. allotment gardens have an energy output similar to the marais with a somewhat smaller total input; however, two-thirds of this input is represented by chemical fertilizer, based on fossil fuel input (Leach, 1975). The results for traditional Chinese peasant farming, (Newcombe, 1976) appear more favourable, but no allowance was included for the energy input in the heavy dressings of animal and human manure. In addition, the very high crop yields presented (12.3 t ha^{-1} rice plus 4.6 t ha^{-1} beans) exceed those hitherto reported for these same crops even when grown separately (Milthorpe and Moorby, 1974).

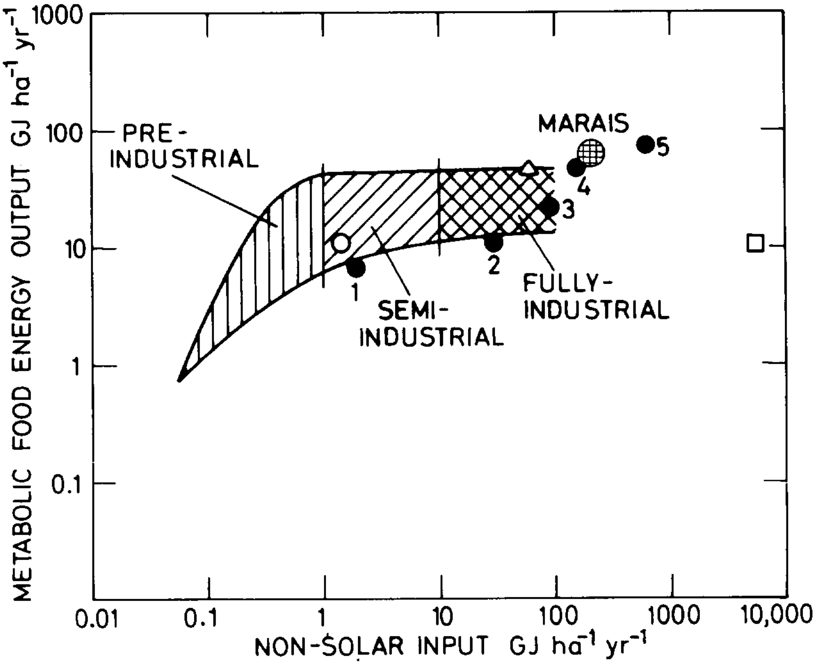

Fig.1. Nonsolar energy input and human food output of agricultural cropping systems. General relationship based on energy budgets of 41 cropping schemes presented by Leach (1975).

• National agricultural systems:
1. Australia (Gifford and Millington, 1975; Gifford, 1974).
2. United Kingdom (Leach, 1975).
3. Israel (Stanhill, 1974, with corrections).
4. Netherlands (Dekkers et al., 1974).
5. Netherlands — horticulture only (Dekkers et al., 1974).

Specialized cropping systems:
○ A Dutch Arable Farm Around 1800 (Dekkers et al., 1974).
△ United Kingdom Allotment Garden (Leach, 1975).
□ United Kingdom Winter Lettuce in Heated Glasshouse (Leach, 1975).

The energy balance of winter salad crop production in heated glasshouses as currently practised in the U.K. has also been given by Leach (1975) and is shown in Fig.1. The energy input for a single crop of lettuce, 4,550—6,060 GJ ha^{-1}, is 20 to 30 times more than the yearly requirement of the marais and the food energy produced is only one-fifth. The energy input used for a perennial, heated glasshouse crop in Israel was calculated to be twice as much again (Stanhill, 1975). Clearly, the energy premium for out-of-season cropping has increased considerably during the last century.

THE URBAN AGRO-ECOSYSTEM

The marais provided a profitable solution to the problem of waste disposal posed by the large number of horses stabled in the city. In 1882 the number of horses belonging to private persons and available for army mobilization was 95,847 (Meissas, 1885). Presumably the total number was considerably larger, but even this number would have produced more than three-quarters of the amount of stable manure estimated to have been used on the marais at that time.

The Parisian maraîchers used this manure to produce 110,000 t of high-value salad and vegetable crops which sold for about ten times the cost of the manure. The surplus growing medium which had to be disposed of annually was only one-twentieth of the volume of manure applied, and was a valuable asset serving to expand and relocate the marais growing area.

The food produced by the system was only sufficient to supply 1.4% of the caloric food energy requirements and 2.4% of the protein requirements of the city's population at that time. However, the volume of fresh salads, vegetables and fruits produced was equivalent to 50 kg per annum per capita, more than present-day levels of consumption of these foods. This supports Kropotkin's claim (1899) that the marais system not only supplied the Parisians with their vegetables, but also provided a surplus for export to London. The extent of these exports was enough to arouse the interest of English horticulturalists in the system (Webber, 1968).

Estimates of the approximate annual fluxes of mass and macroplant nutrients through the Paris urban agro-ecosystem are presented in Fig.2. The boundaries of the system have been extended to include the agricultural land producing the fodder and bedding used for the horses stabled in Paris and supplying the manure for the marais.

The mass of horse fodder and bedding was approximately equal to that of the stable manure applied, whereas only one-fifth of the phosphorus, one-half of the nitrogen and four-fifths of the potassium were so contained. As some 80% of these nutrients contained in feed are excreted by horses (Kligman, 1945), the remaining nitrogen and phosphorus were presumably lost in the approximately half of the excreta voided outside the stables during work. These and other nutrients were, however, utilized elsewhere in a productive system of irrigated agriculture based on the city's sewage system (Meissas, 1885).

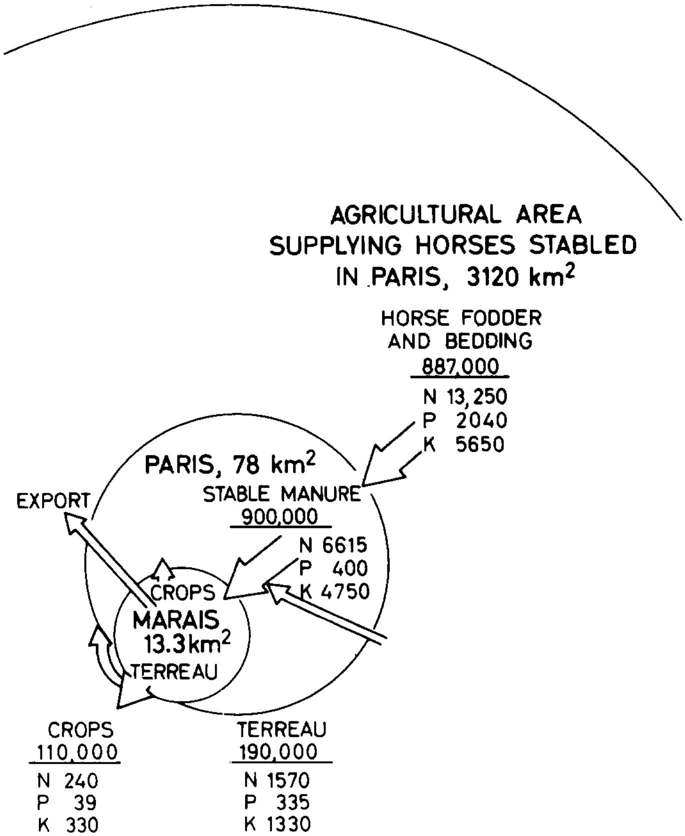

Fig. 2. Mass and nutrient fluxes through the Parisian urban agro-ecosystem in the third quarter of the nineteenth century. Units tons per year, mass (underlined) total fresh weight; major plants nutrients-elemental weight.
Data sources:
(i) Amounts, areas and composition of horse fodder and bedding from Morrison (1949), Brody (1945), Warington (1886).
(ii) Stable manure, composition (Kligman, 1945; Tschierpe and Sinden, 1962) and amount (see appropriate section).
(iii) Terreau, composition (Bretzloff and Fluegal, 1962) and amount (see appropriate section).
(iv) Crops, composition (Chatfield, 1954) and amount (see appropriate section).

Less than one-third of the N applied as stable manure was recovered in the crops and terreau. An unknown amount was lost to the atmosphere as NH_3; such losses may have been larger than the 0.1 t ha^{-1} yr^{-1} found by Denmead et al. (1976) on a grazed pasture, as the production of NH_3 is very noticeable in the early stages of stable manure decomposition.

Leaching of N (and K) following the frequent irrigations applied would account for further losses; indeed, the prevention of nutrient buildup to toxic levels may have been one purpose of the heavy watering regime. The buildup of N in soil organic matter could account for a further considerable weight of the element; thus, the 0.5% N dry weight in marais top soil reported by Courtois-Gerard (1858) equals 15 t N ha^{-1}, five times the annual difference between N application and removal.

More than 90% of the P applied in manure was recovered in the crops and terreau, but less than one-third of the K could be so accounted for. No data on soil concentration of K were found but high values have been recorded in other intensively fertilized cropping systems and such a buildup and leaching presumably accounted for the nonrecovered fraction.

Two-thirds of the mass entering the marais in manure was lost through decomposition, with carbon dioxide, water and heat being released during aerobic fermentation. The quantities involved, calculated approximately from the basic equation for carbohydrate decomposition and the calculated loss in weight of organic matter, were 275×10^3 t yr^{-1} of CO_2 and 112×10^3 t yr^{-1} of H_2O, requiring 200×10^3 t yr^{-1} of O_2. The weights of CO_2 fixed by photosynthesis of the marais crops and of the O_2 released during the process were calculated from values of dry matter production and ash content and found to be 11.6×10^3 t yr^{-1} CO_2 and 8.4×10^3 t yr^{-1} O_2.

The above calculations show the marais formed a sink for O_2 and a source for CO_2. The latter may well have led to elevated local concentrations of CO_2 in the small walled-in holdings; this could have been an important contributing factor to increasing crop growth rates during the winter. The fact that artificially elevated CO_2 levels are now provided routinely for winter salad crop production in northern Europe (Witmer, 1967) supports this possibility.

The heat released from the Paris marais by manure fermentation was estimated at 3.304×10^6 GJ yr^{-1}; expressed as a power density per unit marais area, this value, 6.3 W m^{-2}, approaches those currently released from industrialized and urban areas (Anon., 1971), and is equivalent to 6% of the incident solar radiant flux. Thus the marais may well have been a significant contributing factor to the heat island effect of Paris.

In summary, the crop production system practised by the maraîchers of Paris one hundred years ago added a further and important trophic level to the urban ecosystem, profitably recycling the energy and nutrients produced as unwanted by-products of the city's horse-powered transport system. The positive aspects of this urban agro-ecosystem contrast sharply with the lack of any ecological solution to the problems posed by current urban transport systems — human injuries and deaths, air pollution, and the depletion of irreplaceable fossil fuel and mineral resources.

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