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Traditional Bedouin Agriculture at Petra: Ethnoarchaeological Insights into the Evolution of Food Production

Introduction

This report summarizes certain preliminary results of ethnoarchaeological research on the energetics of traditional Bdūl Bedouin agriculture in the Petra region of southwestern Jordan. That research involved direct ethnographic observations to obtain quantitative labor cost and caloric benefit data on cultivated wheat and barley. These data are relevant to an evolutionary understanding of the principles affecting human subsistence behavior, and hence our understanding of the post-Pleistocene forager/food producer transition.

After many years of research directed at identifying the spatial and temporal origins of food production, modern research has increasingly focussed upon the complex environmental and behavioral processes which presumably led to the forager/food producer transition. Generally accepting that human behavior has evolved in response to changes in the physical and social environment, scholars have isolated environmental setting, climatic variations, demographic shifts and population growth as primary factors significant in the process by which food production strategies evolved. Several popular models currently exist which invoke one or more of these factors to ostensibly account for the evolution of food production.

Unfortunately, while we have identified and stressed the conditions under which the evolution of food production might have taken place, we have failed to adequately address the underlying principles affecting subsistence decisions in general. While several scholars have argued that a better understanding of the conditions under which food production became profitable relative to continued foraging is required, it seems unlikely that significant advances in this direction will occur unless human-animal-plant relationships are investigated within the context of general theories which address the underlying principles affecting subsistence behavior.

In this regard, predictive behavioral models derived from optimal foraging theory as developed by evolutionary biologists and ecologists have been particularly successful in illuminating various aspects of foraging behavior among diverse hunter-gatherer populations. These predictive models invoke decision making based upon the relative energetics (caloric yield/time invested) of exploiting alternative food resources. Unlike alternative predictive models which focus solely upon the yields or "benefits" derived from specific strategies, these particular models explicitly account for the relative labor costs of alternative strategies as well.

Using quantitative data obtained from field observations among the Bdūl Bedouin of the Petra area, the present paper will initially document the utility of such an energetic approach in better understanding the ecological parameters under which early cereal food production strategies would have been practiced. Subsequently, the interpretive insights provided by this approach will be discussed relative to the use of a common archaeological artifact, the sickle blade, in inferring the presence or absence of early agriculture. Initially, some understanding of basic energetic models is required.

Basic Energetic Models

Diet Breadth

Two predictive behavioral models developed by behavioral ecologists which invoke rates of energy capture are particularly relevant to the present study. First, the diet breadth or optimal diet model (Charnov 1976a; Charnov and Orians 1973; Emlen 1966; MacArthur and Pianka 1966; Schoener 1971) predicts which resources a forager should exploit from an array of available resources encountered at random if the rate of energy capture is being maximized. Initially, available resources may be ranked according to the ratio of energy returns each item provides (measured in calories) to the cost (or handling time) of acquiring and processing that item once it has been encountered (= its postencounter return rate). If a forager is maximizing the rate of energy capture, a resource item randomly encountered should be taken if and only if its ranking (return rate) is equal to or greater than the returns to be gained for searching for, finding, and handling an item of higher rank during the same period of time. Resources which fail to meet this criterion should not be taken.

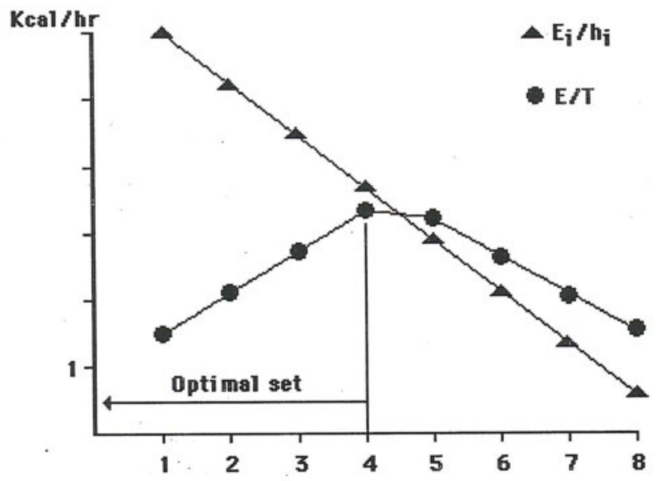
In a more formal statement, for all items to be included in the diet:

$$\frac{E_i}{h_i} \geq E_p$$

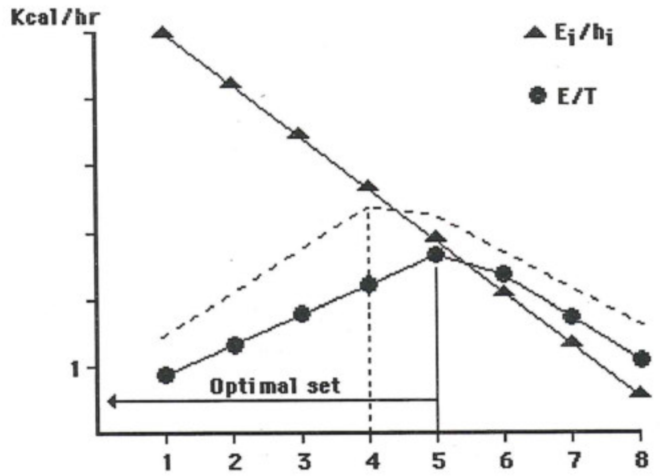
Where E_i = total energy (kcal) of each resource i
h_i = collecting and processing time (g_i+p_i) for each resource i
E_p = $E/(T_s+T_g+T_p)$
E = total energy in resources gathered per collector
T_s = total search time in the resource patch
T_g = total gathering time per collector for all resources gathered
T_p = total processing time per collector for all resources gathered

An optimal diet should include all potential resources with post-encounter return rates equal to or higher than the average returns for foraging in general, and should exclude all potential resources with postencounter return rates lower than average foraging returns. Significantly, whether or not a potential resource is in the optimal diet does not depend upon its own abundance, but rather on the abundance (or more precisely the encounter rate) of higher ranking resources. High-ranked resources should remain in the diet regardless of how rare they become. However, if the encounter rate for high-ranked resources falls, average foraging return rates would also fall and lower ranked resources would enter the diet. These expectations are summarized in FIG. 1.

The diet breadth or optimal diet model is specifically useful for conceptualizing the changes in human diet which apparently occurred in the post-Pleistocene period. As noted by Hawkes *et al.* (1982: 395) and Hill *et al.* (1986), the coincidence between the apparent decline or extinction of large mammal populations and other fauna at or near the end of the Pleistocene and the emergence of "broad spectrum" subsistence economies (Flannery 1969) is consistent with expectations derived from the diet breadth or optimal diet model.



A. Triangles indicate prey types arranged by rank, based on returns once encountered. Circles mark returns gained from searching for and handling progressively lower ranked prey.



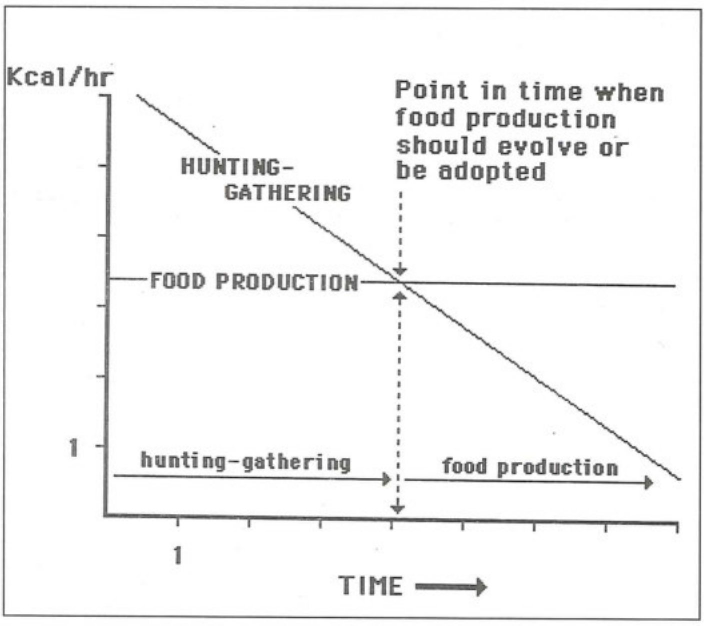
B. If the encounter rate for high-ranked prey decreases, returns from foraging for those prey items should also decrease. As average returns from searching for and handling these resources fall below those gained from handling lower-ranked prey, the latter should enter the diet.

1. Diet breadth model (after Russell 1988: 11, FIG. 1)

Patch Choice

While the diet breadth or optimal diet model specifically deals with the exploitation of resources randomly encountered in a "fine grained" environment, patch-choice models deal with the expected spatial and temporal exploitation of patchy environments where resources are clumped, again assuming that the goal of foraging behavior is to maximize the rate of energy capture (Charnov 1976b; Charnov and Orians 1973; MacArthur and Pianka 1966; Pyke *et al.* 1977; Schoener 1971). Here, it is expected that a forager would operate in that patch or set of patches that produce the best energy returns relative to the time costs of traveling to the patch, searching it, and gathering and processing the resources encountered there. A further expectation of such models concerns movement between patches. Assuming that the foraging process depletes the resource level in any patch through time, it is expected that a forager will only remain in that patch until the rate of energy capture to time invested falls equal to the mean energy return per unit time (including travel time) of all available patches (Charnov 1976b).

This model portends to be particularly useful in addressing issues concerning the forager/food producer transition and the ecological conditions under which food production would have occurred. For example, it has been proposed that under declining foraging return rates at the end of the Pleistocene, food production strategies should have been adopted when mean foraging return rates fell equal to or below the mean return rate for available food production options (Russell 1988: 12). This expected relationship is depicted in FIG. 2.



2. Subsistence strategy return rates and the evolution or adoption of food production options (after Russell 1988:12, FIG. 2). Under declining foraging return rates, food production strategies should have been adopted when mean return rates for hunting-gathering fell equal to or below the mean return rate for available food production options.

Further, it is expected that available food production options should have been adopted according to their ranking by relative return rates. Hence, it has been suggested that cereals which did not exhibit relatively high postencounter return rates for their exploitation in natural stands would have been unlikely candidates for early food production strategies, since the additional labor required for their cultivation would further diminish their rates of energy return to labor expended (Russell 1988: 129-130). Ostensibly, this simple energetic relationship between cereal species would largely account for why so few cereals (29 known or suspected cultivars) became the focus of human food production relative to the vast number of cereal species (roughly 7500) which were, and still are, available for exploitation world-wide.

However, in order to further develop and test this particular proposition in North Africa and the Near East, energetic cost and benefit data is required on the wild progenitors of the relevant cultivated species, the numerous wild cereals and seed resources which various food producing populations continue to exploit, but do not cultivate (Clark 1976: 77-78; 1980: 576; Carruthers 1910: 343; Irvine 1952; Musil 1926: 15-16; 1927: 122-124; 1928: 15-16; Nicolaisen 1963: 179-181, 206-207; Smith 1980: 470-472; Williams and Farias 1972), and any wild cereals and seed resources which are also available to these populations, but are not exploited. Unfortunately, while Harlan's (1967) well-known experimental data on wild einkorn harvesting are widely cited in the archaeological literature, comparable research has not been conducted on the wild progenitors of other cereal domesticates in the Near East and North Africa, let alone on other wild cereal resources. Some initial steps in obtaining such quantitative data in the Petra region have now been made, but those data are still being processed.

The data which are presented here concern a further expectation derived from patch choice models. Specifically, it would be expected that variations in the spatial and temporal exploitation of habitats or habitat types suitable for food production should have been a function of the energy returns for food production effort which could be obtained in specific locations or regions. Quantitative data relevant to this issue as applied to wheat and barley cultivation were obtained by field observations in the area of Petra. These data serve to clarify issues of field selection in early agricultural strategies and associated harvesting techniques.

Locations and Nature of Bdūl Agricultural Fields

The principal areas in which Bdūl agricultural fields were historically located included the ruins of the ancient city to the north and south of the Wādī Mūsā drainage, the southern half of the Petra Valley through Jabal Farasa, the lower Wādī Bayḍa drainage and its surrounding plateau, the low terraces along the Wādī Ṣabra drainage northeast of the ancient site of Ṣabra, and the low terraces of the lower Wādī Mūsā drainage near the site of Ṭūr Imdaī. The Bdūl also cultivated pockets of arable land on the sandstone massifs surrounding the Petra Valley, including fields along the lower slopes of Jibāl ash-Sharāh on the plateau east of Jabal Farasa, the top of al-Khubtha, the plateau on Jabal ad-Dayr, and the broad plateau just below the summit of Jabal an-Nabī Hārūn. Similarly, the Bdūl also cultivated pockets of arable land around the heads of drainages such as Wādī Marwān and Wādī al-Mu'ayṣra to the north-northeast of the Petra Valley, and the southern end of the Wādī ad-Diliyya west of Jabal an-Nabī Hārūn. Although not generally exploited for cereal cultivation, the Bdūl have long tended informal gardens along the bottom of Wādī aṣ-Ṣiyyagh.

Within the ruins of the city of Petra and on the plateau of Jabal ad-Dayr, fields were created by moving structural rubble to the edges of plots in order to cultivate the sandy soils which now bury ancient structures. Ancient walls of ashlar block construction which were not completely buried by sand frequently determined the limits of potential fields, and now lie buried beneath the rubble moved to the margins of the resulting agricultural plots. An early dating of such activities on some fields in the ruins of the city north of the Wādī Mūsā drainage may be reflected by the presence along their margins of coarse, straw-tempered gray-ware sherds, generally dated to the Middle Islamic, Mamluk, or "Medieval" period of roughly the twelfth or thirteenth centuries AD. None of these fields are cultivated today as a result of legislation prohibiting such activities within or near the ruins of Petra.

Many of the outlying Bdūl fields consist of ancient Nabataean rainfall runoff terrace systems along the bottoms of shallow drainages and their more sloped feeder channels. This is particularly true in the southern section of the Petra Valley and on the plateau surrounding the lower end of the Wādī Bayḍa drainage. While some of these ancient terrace systems were intact, others have been partially or totally rebuilt by the Bdūl, often using stones tilled from the fields. At some locations, the Bdūl have created entirely new terrace systems based upon Nabataean runoff principals. Under these conditions, traditional Bdūl agriculture replicated ancient Nabataean, Roman and Byzantine practices in the Petra area. In many instances, however, the Bdūl simply exploit natural pockets of arable land where the topography results in concentrated rainfall runoff from the surrounding terrain. In these instances, Bdūl cereal cultivation is achieved under what are expected to have been prehistoric agricultural conditions.

Wheat and Barley Yields

Seed Stock

Among cultivated, predominantly self-pollinating cereals such as wheat (Frankel and Galun 1977: 18) and barley (Allard *et al.* 1968: 117; Jain 1976: 479), occasional natural hybridization with weed races on the margins of fields occurs, although seldom, if ever, on a massive scale (Harlan 1965: 174; Harlan and Zohary 1966: 1076; Zohary *et al.* 1969). The typical pattern is one involving a localized eruption of a hybrid swarm. Such cases are intermittent in time and space, erupting locally for a generation or two, and then quickly subsiding. Through this process, the locally adaptive traits of weed races are introduced into the cultivated crop. Annual directional selection by humans for seed size and weight in order to isolate the most desirable seed stock for next year's planting has resulted in the creation of ecogeographic landraces of such cereals (see Allard *et al.* 1968: 99-103, 111-113; Russell 1988: 50-53).

In Jordan, several local wheat and barley varieties have resulted from such broadly based mass selection processes, although scientific efforts at improving cereal crops have been formally pursued for several years (Salim 1961). For wheat, where most efforts at cereal improvement have concentrated, only two introduced and developed varieties were in common use in 1988 (El-Hurani 1988: 41). The first is known as F.8, a durum wheat originally introduced to Jordan in 1935 from the 'Akka Agricultural Experiment Station in Palestine. The second is known as *Ḥawrānī Nawaḥī* , another durum wheat, originally introduced to Jordan from the Ḥawrān plains of Syria in 1954. However, these varieties are primarily used in the agriculturally more developed central and northern sections of Jordan, particularly from 'Ammān through Irbid. In southern Jordan, only 12% of the farmers surveyed in 1988 were using them, preferring instead a local variety (or varieties) known broadly as *Qaṭma Ṣafra* (El-Hurani 1988: 41, 42, TABLE 52). This hard wheat landrace, which is cultivated by the Bdūl, is considered relatively low in gluten quality and content, but is high in protein (Salim 1961: 12, 14, TABLE VII).

1986 Yields

In May, 1986, quantitative data on wheat and barley yields were obtained from fields on the plateau south of the lower Wādī Bayḍa drainage, the head of Wādī al-Mu'ayṣra, and the southern Petra Valley. For each field tested, a representative 1 m² of the crop was totally harvested, and both seed and straw/chaff yield were measured using hand-held scientific scales. In three instances, two samples each were taken in order to quantify obvious yield differences in the same field as a result of micro-environmental variations. The results for wheat fields are presented in TABLE 1, while those for barley fields are presented in TABLE 2.

For comparative purposes, TABLE 3 presents the wheat and barley yields expected by Bedouin farmers in the an-Naqab desert in the late 1950s as reported by Mayerson (1960: 18), while TABLE 4 presents the average wheat and barley yields on Arab farms in Palestine according to a British Committee Report of 1930 (Simpson 1930) and TABLE 5 presents expected wheat yields in Jordan according to rainfall regions (Steitieh and Smadi 1974: 19, TABLE 4). As can be seen, the wheat and barley yields observed at Petra in 1986 fall within the "satisfactory" through "exceptional" ranges of yields expected by Bedouin in an-Naqab, and compare favorably with the yields reported for Arab farms in Palestine in 1930 and expected wheat yields in Jordan.

Table 1. Grain and straw/chaff yields (kg) for wheat fields at Petra in May, 1986.

Sample #	Location	PLANT Height (m)	YIELD/M²		YIELD/DUNUM	
			Grain	Straw/Chaff	Grain	Straw/Chaff
W1	L. Wādī Bayḍa	0.72	0.09	0.201	90	201
W2	L. Wādī Bayḍa (same as W1)	0.88	0.158	0.343	158	343
W3	L. Wādī Bayḍa	-	0.066	0.117	66	117
W4	L. Wādī Bayḍa	-	0.04	0.094	40	94
W5	L. Wādī Bayḍa	0.65	0.033	0.04	33	40
W6	L. Wādī Bayḍa (same as W5)	0.94	0.248	0.422	248	422
W7	S. Petra Valley	-	0.095	0.174	95	174
W8	S. Petra Valley	-	0.064	0.079	64	79

Table 2. Grain and straw/chaff yields (kg) for barley fields at Petra in May, 1986.

Sample #	Location	YIELD/M²		YIELD/DUNUM	
		Grain	Straw/Chaff	Grain	Straw/Chaff
B1	Rās Wādī al-Mu'ayṣra	0.072	0.108	72	108
B2	Rās Wādī al-Mu'ayṣra	0.06	0.095	60	95
B3	S. Petra Valley	0.044	0.049	44	49
B4	S. Petra Valley (same as B3)	0.135	0.110	135	110
B5	S. Petra Valley	0.67	0.098	67	98
B6	S. Petra Valley	0.05	0.058	50	58

Table 3. Wheat and barley yield expectations of Bedouin farmers in an-Naqab.

INFORMANT YIELD EVALUATION	WHEAT (kg/du)		BARLEY (kg/du)	
	Sowing Rate	Yield	Sowing rate	Yield
Exceptional	All 5-7	100	All 6-7	200
Good		50-70		70-80
Satisfactory		30-50		40-60
Poor		0-20		0-20

Adapted from Mayerson (1960:18), after Russell (1988:112, TABLE 15).

Table 4. Average wheat and barley yields (kg/du) on Arab farms in Palestine according to a British committee report dated July 13, 1930.

Crop	As Declared in 104 Villages	"Selected Evidence"	"Official Estimate"
Wheat	48	57	67
Barley	63	54	74

Adapted from Simpson (1930: 185, APPENDIX 24), after Russell (1988: 112, TABLE 16).

The Bdūl considered 1986 to be an "average" to "good" year for cereal crops, noting for contrast that 1983 had been "exceptional." Consistent with the findings of agricultural studies in Jordan (Salim 1961: 4, 6, 7-8), the Bdūl maintain that the most critical variables in crop yields are the distribution, timing and amount of rainfall. A related phenomenon involving concentrated runoff and associated depositional processes seemingly underlies observed spatial variations in crop yield within individual fields.

Yield Variations by Microenvironments Within Fields

Two wheat fields in the Wādī Bayḍa drainage and one barley field in the southern Petra Valley exemplified this correlation. In all three cases, field topography involved

Table 5. Estimated production of wheat and area cultivated in Jordan by rainfall regions.

ENVIRONMENT		SOWING RATES AND YIELDS (kg/du)			ARABLE AREA IN AN "AVERAGE" YEAR	
Region	Rainfall (mm)	Sowing Rate	Average Yield	Range of Yields "Bad" – "Good"	Dunums	% of Total Arable
Desert	150-250	4-5	40	10-70	416,000	21.3
Eastern Plain	250-300	5-7	64	35-90	693,000	35.6
Western Plain	300-400	8-15	81	50-117	610,000	31.3
Upland	400+	15	105	75-146	180,000	9.2
Ghawr	irrigated	10-15	147	112-191	50,000	2.6

Adapted from Steitieh and Smadi (1974: 19, TABLE 4), after Russell (1988: 71, TABLE 3).

relatively gentle slopes which concentrated rainfall runoff from larger catchments towards the central and lower portions of fields. As a result, these portions of the fields received greater effective moisture for plant growth, both in quantity of water available and in greater potential permeation of soil. In two of these cases, low, informal rock walls at the lower ends of the fields heightened this process, diminishing soil erosion while simultaneously breaking runoff flow and thus promoting greater water percolation into the soil. In all three cases, the effects of these microenvironmental variations were readily apparent in both the density and height of the resulting crops.

The first example involved a field cultivated in the broad, sandy bottom of a wash with a fairly extensive rainfall catchment. The bottom of this wash had a very gentle slope of around 1-2°, and the runoff pattern along its bottom was highly braided, reflecting the equivalent of "sheet-wash." The sides of this wash were also gently sloping at about 2-3°, but did not receive the same concentrated runoff as the wash bottom.

Wheat growing on the sloped sides of this field was yielding the equivalent of 90 kg/du (sample W1), a respectable yield in light of the comparative data previously presented. However, yields in the central and lower portions of the field where runoff was concentrated were the equivalent of 158 kg/du (sample W2), representing a 76% increase in actual grain yield.

The second example in the Wādī Bayḍa drainage involved a sloped field off the side of the main drainage channel. Here, rainfall runoff was concentrated into the lower central portion of the field, although the total catchment area was relatively small. The lower central portion of the field had a very gentle slope of around 1-2°, while the sides and upper portion of the field had a slightly greater slope of around 2-3°. A low, informal rock wall across the lower end of this field inhibited soil erosion and increased effective moisture immediately behind it in the lower central area. One further result of this constriction of runoff water flow has been the accumulation of silty, clayey loam at this location, a factor which affected both the growth of the wheat itself and the harvesting labor it required. The significance of this observed variation will be further discussed below.

Wheat growing on the sloped sides of this field was yielding the equivalent of only 33 kg/du (sample W5), not a very respectable yield in light of the comparative data previously presented. However, yields in the lower central portion of the field where runoff was concentrated were the equivalent of an astounding 248 kg/du (sample W6), representing a 651% increase in actual grain yield.

That these same relationships between runoff conditions and yields apply to barley is demonstrated by the third example, involving a barley field in the southern Petra Valley. Here, field conditions were somewhat similar to those extant in the second wheat example. The field consisted of gently sloping sandy terrain where rainfall from a relatively small catchment were concentrated towards its central and lower portions. Here again, the central and lower portion of the field had a very gentle slope of around 1-2°, while the sides and upper portion of the field had a slightly greater slope of around 2-3°. Further, a low, informal rock wall across the lower end of the field again inhibited soil erosion and increased effective moisture immediately behind it.

Barley growing on the sloped sides of this field was yielding the equivalent of only 44 kg/du (sample B3), not a very respectable yield in light of the comparative data previously presented. However, yields in the central and lower portions of the field where runoff was concentrated were the equivalent of 135 kg/du (sample W6), a very respectable yield representing a 207% increase.

Yield Variations and the Choice of Cultivation Sites

While the effects which microenvironmental variations within fields have on actual crop yields is readily apparent, it must be noted that such variations occur without any equally dramatic genetic variation within the crops

Table 6. Standard analyses and caloric variations of wheat and barley samples from the same fields but different ecological conditions.

SAMPLE #	ENERGY KCAL/KG	COMPOSITION (%)					
		Protein	Carbohydrates	Fat	Ash	Fiber	Moisture
W5	3545	11.74	73.34	1.57	0.93	4.80	7.62
W6	3477	9.30	73.90	1.65	2.05	4.67	8.43
B3	3314	10.67	67.94	1.88	1.66	11.73	6.12
B4	3313	13.46	64.84	2.01	1.84	11.42	6.43

themselves. Each of the fields examined were sown with the same general stock of seeds, and the variations observed were solely the result of the microenvironmental conditions documented. Standard analyses of the harvested wheat and barley further indicate that while compositional variations in total protein, carbohydrate and fat content between samples from the same fields do occur, significant caloric variations do not (TABLE 6).

Annual grasses in general have evolved to achieve mass representation and seed production in temporally favorable environments (Cohen 1971; Paltridge and Denholm 1974). A significant aspect of this adaptive strategy is enormous phenotypic plasticity in their potential for seed production (Allard 1965: 76). For wheats and barleys, as with wild grasses and rangelands in general, water and soil nutrients represent the primary limiting factors to plant growth and productivity (Breman and de Wit 1983; Guise 1969; Hall *et al.* 1979; Hillman 1973: 230; Simpson 1981; Webley 1972: 173). Under conditions of seasonally restricted rainfall, water stress is particularly significant in reducing crop yields and rangeland productivity. It is therefore hardly surprising that the yield from the same seed on different parts of the same field would exhibit extremes according to microenvironmental variations involving water concentration.

It has been previously demonstrated that the yields of mass selected landraces of wheat grown under dry-farming conditions fall within the upper range of yield variability exhibited by natural stands of wild wheat (Harlan and Zohary 1966: 1078; Russell 1988: 48-50; Zohary 1969: 56). Further, it has been documented that, prior to the development of the first wheat hybrids in AD 1795, wheat yields cannot be demonstrated to have significantly increased since at least the first century AD (Russell 1988: 43, 48-53).

Hence, while it is reasonable to posit that annual selection by humans for seed size and weight among predominant self-pollinating cereals served to stabilize mean productivity within the upper range of variability exhibited by their wild progenitors, the present data support the contention (Russell 1988: 66-67) that it was the selection of favorable cultivation sites which would have dramatically increased overall cereal productivity.

Hand Harvesting

Introduction

The Bdūl harvest their cereal crops by hand rather than by sickle. The harvesting of cereals by hand represents the oldest and most long-lived reaping method, and is widely practiced, not only in the Petra area, but throughout the Old World (Bohrer 1972). This ethnographic observation is significant in addressing the evolution of early food production strategies, since the presence or absence of sickle blades in the archaeological record has often served as the principle criteria for inferring the presence or absence of cereal cultivation.

In May and June, 1986, quantitative data on the labor costs of harvesting wheat and barley by this method were recorded in fields on the plateau south of the lower Wādī Bayḍa drainage and in the southern Petra Valley. During this period, fields were being harvested by the Bdūl in groups ranging in size from the few members of a single household through 10-20 individuals from related families and their friends.

The hand harvesting of wheat and barley grown on the typical sandy soils which characterize most fields in the Petra area proceeds in a squatting position, with both hands employed. The tillers of grain in an area the size of an extended hand are grasped between the thumb and forefingers just above soil level, with the tillers pressed against the palm by the forefingers. A short jerk backwards with the hand, accompanied by a slight downward tilt of the wrist, snaps the stalks from their roots. Both dry and slightly green stalks will snap as a result of this hand action.

Work proceeds in this fashion until both hands are filled with small bundles of grain, at which point the bundles are laid together on the ground and work again proceeds with empty hands. The small piles of reaped grain are later gathered for transport to a threshing floor. The gathering is often performed by an adolescent or teenager. The only exception to this reaping procedure was observed when the patch of tall wheat where sample W6 was obtained was harvested. This patch of wheat, growing in silty, clayey loam, would not snap off at its base, and stalks were literally jerked from the hard soil a few tillers at a time. Penetrometer readings across this

Table 7. Penetrometer readings in the wheat field in the lower Wādī Bayḍa where samples W5 and W6 were obtained.

Sample #	Location	PENETROMETER READING (KG/CM^2)					
		1	2	3	4	5	RANGE
W5	Slope of Field	1.00	0.75	1.00	0.75	1.25	0.75-1.25
W6	Center of Field	3.75	3.85	> 5.00	> 5.00	4.00	3.75- > 5.0

Table 8. Efficiency of Bdūl males hand harvesting wheat and barley near Petra in May and June, 1986.

DATA	SUBJECT			
	1	2	3	4
SUBJECT'S AGE	45-48	45	20	30
CEREAL	Barley	Wheat	Wheat	Wheat
FIELD LOCATION	S. Petra Valley	L. Wādī Bayḍa	S. Petra Valley	L. Wādī Bayḍa
SAMPLE #	B5	W4	W8	W6
KG/DU	67	40	64	248
NO. OF M^2 TIMED	20	4	12	4
MINUTES/M^2				
Mean	1.1	0.64	0.65	2.68
Median	1.1	-	0.63	-
St. Dev.	0.22	-	0.2	-
Min.	0.83	0.6	0.4	1.6
Max.	1.5	0.8	1.0	3.7
KG GRAIN/HR	3.66	3.74	5.94	5.58
KCAL/HR *	12,078	13,090	20,790	19,530
MEAN HRS/DU	18.3	10.7	10.8	44.7

* Calculated for barley at 3300 Kcal and wheat at 3500 Kcal. This excludes all prior tillage and sowing labor costs, and all subsequent processing labor costs.

field dramatically document this observed variation in soils (TABLE 7).

Quantitative Labor Data

To obtain quantitative hand reaping labor data, a representative focal person was chosen and timed by stop watch, recording the time elapsed for each m^2 of crop harvested. The purpose and nature of the recording were not revealed to the focal person, and in two cases, the recorder pretended to be observing a harvester other than the focal person. In four cases, harvesting labor was determined in fields for which grain yields had been previously established. The results of these four cases are presented in TABLE 8.

Initially, the opportunity only arose to repeatedly time one individual who was hand harvesting barley (subject 1), with the results suggesting a mean efficiency of 18.3 hours per dunum on sandy soils. The only comparable data was obtained for a 25-28 year old male who was hand harvesting barley in a field with similar soils just east of the head of Wādī al-Mu'ayṣra, but only his labors on a 2 m^2 area were timed, and the yield of the field involved was not determined. Even so, he harvested the first m^2 in 1.35 minutes, and the second in 1.57 minutes (mean of 1.46 min/m^2). This would equate with an efficiency of 24.3 hours per dunum, although it should be noted that timing was terminated because the subject was more interested in having a conversation with the recorder than in harvesting his barley crop. A labor expenditure of 18.3 hours per dunum for the hand harvesting of barley grown on sandy soils with very little clay or silt therefore seems reasonable.

Three separate determinations were made for the labor expended in the hand harvesting of wheat. Two of these (involving subjects 2 and 3) were in fields possessing sandy soils with very little clay or silt, while the third (involving subject 4) was in the tall wheat plot (W6) growing in silty, clayey loam. As mentioned above, the standard method used to hand harvest cereals growing elsewhere on sandy soils did not work here, and the stalks were actually jerked from the hard soil a few tillers at a time. The resulting differences in the labor required are readily apparent. Subjects 2 and 3 worked at relatively comparable paces, resulting in the close expenditures of 10.7 and 10.8 hours of labor time per dunum, even though the density of crops being harvested were 40 and 64 kg/du respectively. By contrast, subject 4 expended tremendous labor in harvesting the tall wheat plot growing in silty, clayey loam, suggesting a labor requirement of 44.7 hours per dunum of wheat growing in these conditions. In addition to occasional expletives, subject 4 repeatedly mentioned that he wished he had a sickle.

Efficiency of Hand vs. Sickle Harvesting

The possibility of a correlation between hand vs. sickle harvesting as related to cereals grown on sandy vs. dense soils was suggested by Bohrer (1972). Apparently, cereals grown in loose sandy soils tend to develop shorter, weaker stalks and a more clumped root base, while cereals grown in denser, clay soils tend to develop taller, stronger stalks and a more diffused root base. These aspects of the phenotypic flexibility of cereals would directly affect human harvesting strategies as a function of the environments in which they are grown. The hand harvesting labor data presented in TABLE 8 appear to support this relationship.

Comparative labor data on the reaping efficiency of various prehistoric sickles with lithic blades are given in the replication studies of Steensberg (1943), where plots sown with two-rowed barley and a small percentage of oats were harvested, and in the studies of Korobkova (1981), where plots of wheat were harvested. These studies primarily involved reaping experiments with replicate sickles, using both ancient and modern lithic blade inserts. TABLE 9 summarizes their efficiency data on various forms of early sickles, including additional efficiency data for replicas of early metal sickles, and ethnographic and historic data on the use of modern iron sickles.

For the earliest cereal strategies, a sickle reaping efficiency of approximately 24-33 hrs/du seems appropriate. By later periods, refinements in sickles with lithic blades had seemingly reduced reaping labor to approximately 15-20 hrs/du. Apparently, the labor efficiency of early forms of metal sickles (18-23 hrs/du) was not necessarily greater than developed forms of sickles with lithic inserts, although later iron sickles had a reaping efficiency of approximately 8-11 hrs/du, and modern forms between 2-5 hrs/du.

As can be seen, the reaping efficiency documented for a Bdūl hand harvesting barley in the sandy soils which characterize the Petra and Bayḍa areas falls within the lower range of labor recorded for reaping with advanced lithic and early metal sickles. Even the Bdūl who was less concerned with his barley reaping than conversing with the researcher was operating at an efficiency within the lower range of labor recorded for reaping with early lithic sickles, and close to the upper range of labor recorded for reaping with early metal sickles.

This relationship is even more pronounced when comparisons are made with the labor recorded in hand harvesting wheat grown on sandy soils. The reaping efficiencies documented for Bdūl hand harvesting wheat in the sandy soils which characterize the Petra and Bayḍa areas indicate that they spend less labor time than that documented for harvesting with all lithic and early metal sickles. Their efficiency actually falls within the upper range of labor recorded for reaping with early and traditional iron sickles. By contrast, the Bdūl harvesting the tall wheat plot growing in silty, clayey loam was operating at an efficiency less than using either an unhafted piece of obsidian without secondary flaking, or a primitive straight sickle with two flint inserts.

These data indicate that in both prehistoric and historic contexts, there has been less reason for wheat or barley grown on sandy soils to be harvested with sickles than wheat or barley grown on denser clay soils. Significantly, the primary focus of early cereal cultivation in the Near East, North Africa, Central Asia and Europe was on light soils (Russell 1988: 66-67; Sherrat 1980: 315; 1983: 98), such as those in the vicinity of Bayḍa and Petra.

Archaeological Implications

The phenotypic plasticity of unimproved, mass-selected land races of wheat and barleys is such that extremely high yields are possible under favorable ecological conditions. Given their predominant self-pollinating reproductive strategies, productivity in early wheat and barley cultivation would have been manipulated by choice of cultivation site, not by selective plant breeding. Attempts to explain the evolution of cereal production strategies on the basis of complex feedback mechanisms involving increased productivity as a result of human selective breeding (e.g. Rindos 1980; 1984) do not appear to be tenable for predominant self-pollinating cereals.

These data therefore provide a quantitative basis for the expectation that environments with suitable soils and natural concentrations of runoff would have been the focus of early cultivation strategies (Russell 1988: 66-67). Actually, the primary focus of early cereal cultivation in the Near East, North Africa, Central Asia and Europe does appear to have been on light soils with low water-retaining capacities (Clark 1968: 97; Sherrat 1980: 315; 1983: 98; Simpson 1981: 27; Webley 1972: 171, 173). However, the locations where such light soils were exploited for early cereal cultivation were almost universally associated with localized surface water or high groundwater, resulting from perennial spring flows, spate runoff on alluvial fans, concentrated runoff in catch-

Table 9. Relative reaping efficiencies of prehistoric through modern hand sickles.

DESCRIPTION/TYPE OF SICKLE	HRS/DU	SOURCE
Obsidian piece without secondary flaking	41.6-33.3	Korobkova 1981: 340
Flint, curved blade with secondary flaking	31.6	Steensberg 1943: 23
Flint, straight blade with secondary flaking	24.6	Steensberg 1943: 23
Early Djeitun sickle with 2 flints	41.6-33.3	all Korobkova 1981: 340
Early Djeitun sickle with 3 flints	33.3	
Sickle with 3 obsidian inserts	33.3	
Sickle with 2 flints with secondary flaking	27.8	
Sickle with 5 obsidian inserts	27.8	
Stenild sickle with ancient flake	26.7	Steensberg 1943: 23
Stenild sickle with modern flake	36.5	Steensberg 1943: 23
First Yalangach-depe/Stenild sickle	23.8	Korobkova 1981: 340
Second Yalangach-depe/Stenild sickle	23.8	Korobkova 1981: 340
Crescent-shaped, 1 flint sickle	20.0	all Steensberg 1943: 23
Crescent-shaped, 1 flint sickle	25.6	
As above, with straight toothed edge	27.0	
Late Djeitun, 2 inserts with denticulation	18.5	Korobkova 1981: 340
Late Djeitun, 3 inserts with denticulation	18.5	Korobkova 1981: 340
Early Tripolye with 4 flint inserts	18.5	all Korobkova 1981: 340
Early Tripolye with 5 flint inserts	18.5	
Shomu-tepe with obsidian inserts	16.7-18.5	
Curved horn sickle with flint inserts	16.7-18.5	all Korobkova 1981: 340
As above but with longer blade	16.7-18.5	
Late Tripolye with sawtooth flaking	15.2	
Bronze crescentric, serrated edge	19.3-22.8	Steensberg 1943: 23
Bronze knob-sickle, smooth edge	20.0-23.0	Steensberg 1943: 23
Copper, cold-forged, half-moon sickle	18.5	Korobkova 1981: 340
Iron, smooth-edged Slovakian sickle	10.7	Steensberg 1943: 23
Iron, serrated Galician sickle	8.7	Steensberg 1943: 23
Iron, serrated edge	8.8	Korobkova 1981: 340
Iron, smooth-edged, small size sickle	8.0-16.0	Avitsur 1966: iv
Iron, smooth-edged, medium size sickle	8.0	Avitsur 1966: iv
Iron, smooth-edged, large size sickle	2.7-4.0	Avitsur 1966: v
Iron, 1829-1830 sickles, barley->wheat	4.1->4.9	U.S. Dept. of Labor 1899
Iron, smooth-edged, very thin wheat stand	1.6	Lerche 1968: 37

Adapted from Russell (1988: 116, TABLE 20).

ments, and flood-recession environments around ponds, marshes, lakes and streams (Moore 1985: 15-16; Russell 1988: 66-67; Sherrat 1980).

Significantly, such favorable locations are, in general, geographically circumscribed. It is therefore suggested that, coupled with the attributes of sessile and stored resources, such locations would have been (or would have become) a focus of competition between human populations. Consistent with evolutionary models of territoriality invoking economic defendability (Dyson-Hudson and Smith 1978; Krebs and Davies 1985: 86-88), it seems reasonable to expect that the high return rates which could be obtained by cultivating cereals in circumscribed environments with rich soils and natural or easily obtained irrigation would have provided a situation in which the benefits derived from permanently occupying and exploiting them outweighed the social costs of their exclusive use and defense.

Finally, from the data presented above, it seems unreasonable to infer that an absence or low frequency of sickle blades in archaeological contexts involving sandy environments necessarily indicates that cereal cultivation was not practiced. The hand-harvesting of cereals on loose, sandy soils is energetically as efficient, if not more so, than sickle harvesting under similar conditions. Only on denser, clay soils is sickle harvesting necessarily more efficient than hand harvesting. Hence, while the presence of sickle blades in archaeological contexts set in clayey environments may indeed be an excellent marker for the expansion of early cereal cultivation into these regions, their absence at sites in sandy environments has little to do with the presence or absence of cultivation.

It has been previously suggested that the early aversion to heavier clay soils may be partially understood by reference to early tillage technology and the labor required for seedbed preparation, since light soils would be inherently easier to cultivate with hand tools than the denser clay soils (Sherrat 1980: 321; 1981: 293; Simpson 1981: 27; Webley 1972: 171, 173). It has also been noted that the frequent association of clay soils with forest growth would presumably have made the exploitation of such lands less attractive than those with lighter soils under conditions of lithic technology due to the higher labor costs expected for initially clearing (Iversen 1956; Kaplan 1985: 12) and subsequently breaking dense virgin clay soils. It now appears that a further cost associated with the exploitation of such soils was increased harvesting labor.

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