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Effects of banqueting on water infiltration and physico-chemical properties of soil in semi-arid lands

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15 **Effects of banqueting on water infiltration and physico-chemical properties of soil in semi-**
16 **arid rangelands**

17

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38

39 **Abstract**

40

41 Banqueting is a simple and cheap soil conservation practice in natural rangelands under dry
42 climates. Little research exists about its impacts compared to other land uses, where agriculture
43 and land abandonment may be important reasons for degradation. This study has evaluated water
44 infiltration and key physico-chemical properties of soil in natural rangelands with banquets in
45 West Azerbaijan (North-Western Iran) compared to: (i) undisturbed sites (assumed as reference
46 condition) and (ii) cultivated or abandoned dry farmlands. Under these soil conditions, the
47 texture, bulk density, porosity, water content, pH, electrical conductivity, organic carbon and
48 carbonate contents of soil (using common physical-chemical methods) as well as the hydraulic

49 conductivity (using a single-cylinder infiltrometer) were measured in the topsoil (0 - 20 cm).
50 This data was further processed by applying the Principal Component Analysis and the
51 Agglomerative Hierarchical Cluster Analysis. In areas with banquetts, soil hydraulic conductivity
52 was higher by 84% compared to dry farmlands (abandoned or not), where water infiltration was
53 noticeably reduced (-44%) compared to the reference soil condition. Moreover, a noticeable
54 increase in organic carbon content (+80%) and a lower salinity (-36%) of soil compared to
55 cultivated areas was measured. These effects are important to enhance soil fertility on one side,
56 and resistance to erosion on the other side. Therefore, in the experimental areas, banquetting may
57 counteract the degradation of soil due to the agricultural activity as well as its abandonment, and
58 restore the properties of the undisturbed soils that are typical of natural rangelands. The results of
59 this study may be of help for landscape managers and agronomists for the pressing needs for soil
60 conservation and productivity in semi-arid areas that are prone to degradation and abandonment.

61
62 **Keywords:** dry farmland; land abandonment; natural rangeland; soil hydraulic conductivity; soil
63 organic carbon; topography control.

64

65 **1. Introduction**

66

67 Soil conservation is essential in areas under different land uses, in order to limit surface runoff,
68 erosion and degradation. Conservation strategies also help to support soil quality and
69 functionality (Lucas-Borja et al., 2022), which is beneficial for preservation of vegetation cover
70 and diversity as well as for provision of many ecosystem services (Allan et al., 2015). The soil
71 conservation techniques are many, and their effects depend on site characteristics, such as
72 climate, land morphology, vegetation, and soil properties (Maetens et al., 2012).

73 Soil conservation techniques may be less successful in semi-arid and arid areas compared to
74 other climatic and geomorphological contexts, due to the peculiar climate and soil characteristics
75 (heavy and non-frequent rainstorms, long and dry periods, shortage of soil organic matter and
76 nutrients, low depth of soil profile, Camarasa-Belmonte et al., 2020). This means that, in semi-
77 arid and arid climates, the effectiveness of each technique at restoring soils requires specific
78 investigations site by site.

79 The effects of the different soil conservation techniques (e.g., mulching with vegetal residues,
80 terracing and tillage) on surface runoff and soil erosion rates have been explored by ample
81 literature, also in several semi-arid sites. Fewer investigations have been carried out on the
82 effects of these techniques on the characteristics of soils. This is an important issue, since the

83 hydrological and erosion response to treatments strictly depends on many physical and chemical
84 properties of the treated soils (Bastida et al., 2008). For instance, soil hydraulic conductivity is a
85 key parameter of soil that influences the runoff and erosion processes (Jarvis et al., 2013), since a
86 reduction in water infiltration may increase runoff generation (and thus the flooding risk) and
87 consequently on-site and off-site transport of sediments. Stable aggregates can increase soil
88 macroporosity with consequent higher infiltration of rainwater and lower detachment of soil
89 particles (Pierson et al., 2014). Furthermore, an increase in organic matter and a decrease in
90 salinity of soil are beneficial for plant growth and productivity (Zema et al., 2019). A better
91 understanding of changes in soil properties due to the application of soil conservation techniques
92 in semi-arid areas affected by severe degradation due to highly-intensive land uses may support
93 the task of landscape managers and agronomists, in order to assess the post-treatment conditions
94 for crop production and environmental protection. This knowledge is particularly needed in areas
95 affected by high rates of land degradation due to the specific morphological and climatic
96 characteristics. This is the case of West Azerbaijan, a semi-arid area of Northern Iran that is
97 traditionally devoted to grazing, but, at the same time, affected by severe land degradation and
98 exposed to hydrogeological hazards. Here, several lands have been treated with construction of
99 “banquets”, small structures (in some cases with plants on their edges) aiming at locally reducing
100 soil slope, in order to limit water and sediment flows. This soil conservation technique consists
101 of the following steps: (i) small holes are dug into the soil; (ii) the excavated soil is positioned
102 along the contour lines to build small U-shaped or semi-circular (the banquets) terraces with
103 berms; and (iii) herbs are planted or naturally grow on the edge or within the terraces.

104 Banquets create terraces with a milder longitudinal profile compared to the surrounding areas.
105 Moreover, when plants grow on the terrace edge, these patches act as an obstacle against the
106 water and sediment flows, and entrap part of the soil load from upstream. Banquets commonly
107 work as small transverse structures, such as check dams. Compared to linear dams, the
108 semicircular shape of banquets results in a lower height on their sides. This reduces the hydraulic
109 jumps and therefore the impacting effect of falling water. Moreover, the water stream
110 overpassing the terrace edge adheres to the berm profile (slightly steeper compare to the local
111 sloper upstream), avoiding a hydraulic jump as for the vertical check dams (which may results in
112 local erosion). The change in longitudinal slope increases sedimentation upstream of each
113 structure, and this results in an enrichment of topsoil in finer particles (with increases in organic
114 matter content adsorbed by these particles) (Bombino et al., 2008). It is well known that water
115 infiltration, moisture and retention capacity of soil are associated to organic matter content of
116 topsoil (e.g., Boyle et al., 1989; Wuest et al., 2005), but also other physico-chemical properties

117 of soil may be impacted by banquets, such as texture, porosity and bulk density, but also pH,
118 electrical conductivity, and calcium carbonates, by redistribution of soil compounds/elements by
119 the banquet effects on the characteristics of the overland flow (e.g., (Caravaca et al., 2004;
120 Shabanpour et al., 2020). This means that the construction of these small transverse structures
121 can improve key physico-chemical and many hydrological properties of topsoil (Lucas-Borja et
122 al., 2021; Zema et al., 2018). However, excessive sedimentation may create soil crusting and
123 undersaturated water flow. The latter effect could increase the erosion power of runoff (due to its
124 higher transport capacity) downstream of each banquet with local erosion (Fortugno et al., 2017),
125 while soil crusting may decrease water infiltration upstream of the structure (Hillel, 1998).
126 Therefore, this technique should to be cautiously applied by land managers after a careful
127 evaluation of the morphological effects resulting from banquet installation.

128 Surprisingly, the literature about the physical, chemical and hydrological properties of soils in
129 areas treated with banquets is very scarce. Ayoubi et al. (2022) evaluated soil properties after
130 banqueting in hilly apple orchards in Central Iran, stating that this restoration technique may
131 improve soil quality in cultivated lands of the semi-arid regions. The effects of banqueting in
132 fire-affected rangelands on soil carbon sequestration were investigated by Faraji et al. (2019) in
133 East Azerbaijan (Iran), showing that the decline in organic carbon amount due to fire can be
134 contrasted by this technique. More recently, the same authors explored the impacts of fire and
135 banqueting on plant functional groups in the same environment, demonstrating that banqueting
136 with seeding had a positive effect on the vegetation characteristics of the region, while fire
137 shows contrasting effects (Faraji et al., 2020).

138 To fill the research gaps following the scarce literature on banquets, this study has studied the
139 effects of banqueting on key physico-chemical and hydrological properties of soils - with a
140 special attention to water infiltration - through a case study in West Azerbaijan (Northern Iran)
141 eight years after banquet construction. More specifically, this study has evaluated: (i) the
142 changes in the main physico-chemical (texture, porosity, bulk density, pH, electrical
143 conductivity, organic carbon and carbonate contents) and hydrological (hydraulic conductivity
144 and water content) properties of the treated soil among plots installed in natural rangelands with
145 banquets, undisturbed rangelands (the latter assumed as reference soil condition), and abandoned
146 or cultivated farmlands; and (ii) the differences in the ensemble of the studied soil properties
147 among the aforementioned land uses using multivariate statistical techniques. To the authors'
148 best knowledge, this is the first study that has explored the effects of banqueting on the main
149 physico-chemical properties of soil in delicate ecosystems under arid conditions. Therefore, this
150 study contributes to fill the scarce literature about a promising technique for soil conservation,

151 due its simplicity and cheapness, which make banqueting - and, more in general, techniques
152 based on topography control, - advisable for application in arid environments. Of course, the
153 results of this study must be considered as preliminary, since the investigation has been carried
154 out under specific experimental conditions, and the dataset of soil properties is not exhaustive in
155 view of a more complete analysis of the environmental effects of banqueting.

156

157 **2. Materials and methods**

158

159 *2.1. Study area*

160

161 The study was carried out in autumn 2022 in a small watershed (“Khangah Sorkh”, Urmia, West
162 Azerbaijan, North-Western Iran, 37°46'16.5"N; 45°00'12.5"E) with three land uses (natural
163 rangeland, abandoned dry farming and dry farming) at an altitude between 1440 and 1650 m
164 a.s.l.. The climate of this area is cold semi-arid, BSk type according to Koppen’s classification
165 (Kottek et al., 2006). Winter is cold, while summer is dry and relatively hot. Precipitation is
166 mainly concentrated in late autumn and spring, scarce in summer, and snowy in winter. The
167 mean annual temperature and precipitation are 9.9 °C and 393 mm/yr, respectively.

168 The vegetation of the region is shrubland and grassland, with *Astragalus* spp., *Agropyron* spp.
169 and *Bromus* spp. as dominant species. Soils are mainly Typic Haploxerept (classification of
170 (WRB-IUSS, 2015), with a sandy loam texture (54% of sand, 28% of silt and 18% of clay).

171 A hydrological characterization of the watershed, based on recent data measured by Bureau of
172 Natural Resources and Watershed Management of West Azerbaijan Province (Iran) in 2023
173 shows average annual flow of 125 mm, and soil loss and sediment yield of 17.7 and 5.65 tons/ha,
174 respectively.

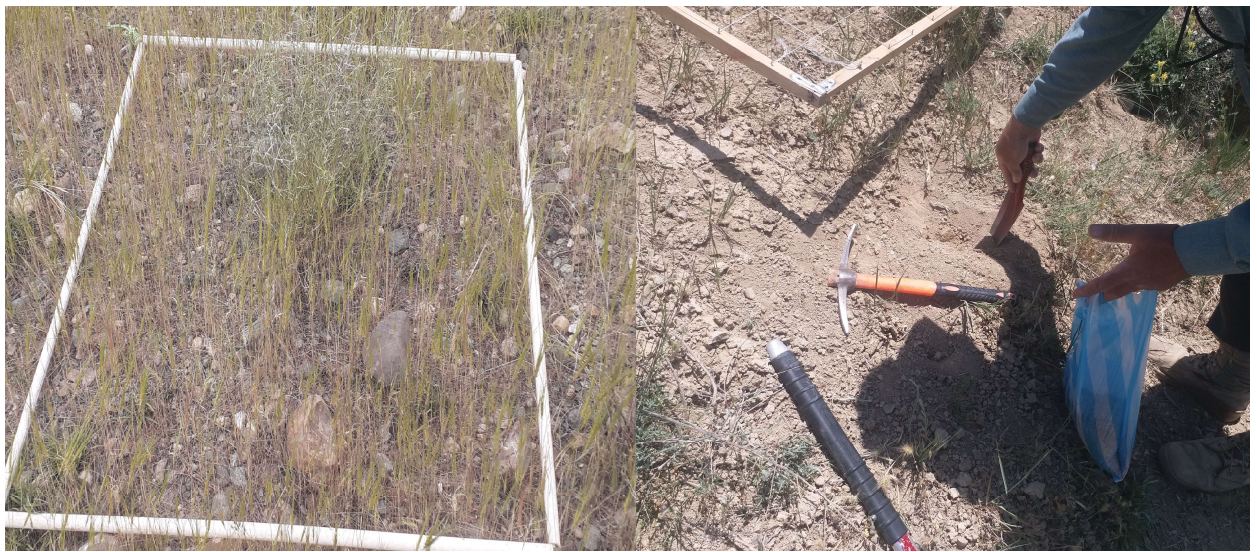
175



176

177

(a)



178

179

(b)



180

181

(c)



182

183 (d)Figure 1 – Aerial image of the experimental site (a), s measurement plot (d), details of
184 banquets (b), and landscape (c) (Khangah Sorkh, West Azerbaijan, Iran).

185

186 2.2. *Experimental design*

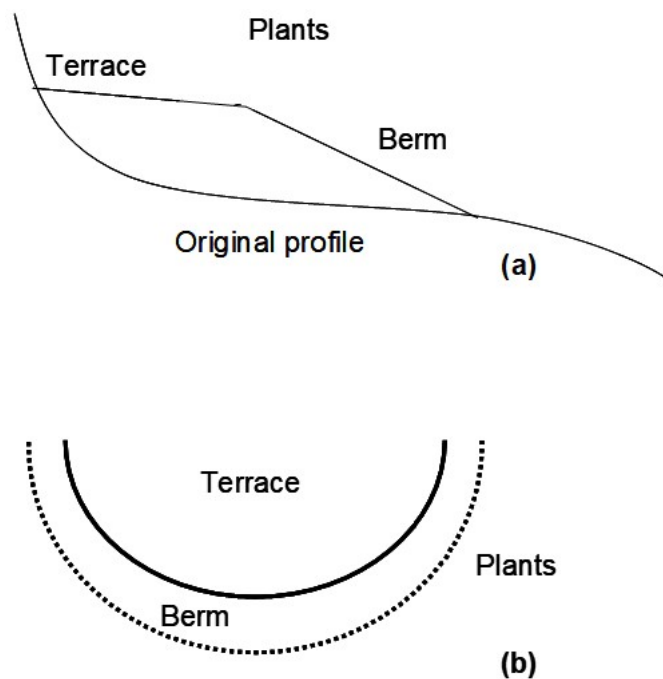
187

188 An experimental site of about 3 ha was identified in the study area with a mean slope between
189 20% and 25% in the watershed (Figure 1a). In this site, five plots were randomly selected in each
190 of four areas with the following soil conditions (Figure 1b): (i) natural rangeland treated with
191 banqueting (hereafter indicated with “B”); (ii) dry farming cultivated with wheat (DF), where
192 seeds are distributed on tilled lands and are not irrigated; (iii) abandoned dry farming (about 3
193 years before the experiment) (ADF); and (iv) natural rangeland (NR, assumed as “reference”
194 condition, as being the only undisturbed area in the absence of anthropogenic activities). Plots

195 were located at a minimum reciprocal distance of 100-200 m, in order to avoid pseudo-
196 replications.

197 Banqueting was carried out by digging a series of holes (diameter and depth of 40 cm). After
198 excavation, the soil was manually placed along the contour lines of the hillslopes, to build a
199 structure (the banquet) with a semicircular shape (diameter of 120 cm and interspace of 4 m
200 between two consecutive banquets) (Figure 1c). The depth between the upstream and
201 downstream edges of each banquet was about 0.4 m. The position of banquets along two
202 consecutive contour lines was alternated (along a “zig-zag” longitudinal profile), and the density
203 of banquets was approximately 200 structures per hectare (Figure 1d). Small plants of
204 *Amygdalus* spp. and *Quercus* spp. naturally grew on the banquet edge after construction (Figure
205 2).

206



207

208 Figure 2 – Sketch of profile (a) and map (b) of a banquet.

209

210 2.3. Soil sampling and analysis

211

212 In each of the five plots under the individual soil conditions, five soil samples (each of 500 g)
213 were randomly collected in the layer between 0 and 20 cm, where the banquets primarily exert
214 their effects. A steel ring (0.1 m and 0.05 m in diameter and height, respectively) was used for
215 sample extraction, and a composite sample was then prepared after mixing the five sub-samples.

216 After collection, the soil samples were transported to the laboratory for the analysis, and stored at
217 4° C. Then, the samples were air-dried and sieved through a 2-mm mesh before soil analysis.

218 The following physico-chemical properties were determined on the composite samples: texture
219 (clay, silt and sand contents), porosity (SP), bulk density (BD), saturated water content (SWC),
220 pH, electrical conductivity (EC), organic carbon (OC), calcium carbonate equivalent (CCE). In
221 more detail, about the physical properties, soil texture was determined by the Bouyoucos method
222 (Gee and Or, 2002), BD by the core method (Blake, 1965), and SP and SWC by the gravimetric
223 method. Among the chemical properties, pH and EC were measured in a paste of saturated soil
224 with common portable probes, OC using wet oxidation (Walkley and Black, 1934) method, and
225 CCE by back titration (Loeppert and Suarez, 1996).

226

227 *2.4. Measurements of soil hydraulic conductivity*

228

229 Soil hydraulic conductivity (SHC) was measured at each plot by a small single-cylinder
230 infiltrometer (diameter of 20 cm and height of 30 cm). A single-cylinder device was used, in
231 order to allow also horizontal components of infiltration velocity, which can better capture the
232 field conditions for water infiltration compared to double-ring infiltrometers (which vertically
233 confines the infiltrating water within an external saturated layer). The base of the infiltrometer
234 was placed at a depth of 20 cm under the soil surface. After positioning, the infiltrometer was
235 filled with water, and the infiltration time was immediately measured until 1500 mL of clear
236 water infiltrated at a constant hydraulic head (by a continuous refilling). The infiltrated volume
237 was measured until three equal time records throughout filling operations. The ratio between the
238 water depth and the time recorded for water infiltration gave the soil infiltration rate. The
239 infiltration measurements were made in three randomly-chosen points of each plot. For the B
240 plots, one and two points were selected downstream and upstream of the banquet edge,
241 respectively.

242

243 *2.5. Statistical analysis*

244

245 The measured values of the SHC and other physico-chemical properties of soil were processed
246 using a one-way ANOVA, to identify statistically significant differences among the four soil
247 conditions (adopted as independent factors with four levels, B, DF, ADF and NR). If significant
248 differences were found for a particular variable, a Tukey test (at $p < 0.05$) was used to determine
249 which treatments were different. Before the ANOVA, normality and homogeneity of variance

250 were checked with the Shapiro-Wilk test and Levene's test, respectively. If the tests were not
 251 satisfactory, the data were square-root transformed before running the ANOVA again.
 252 Then, a combination of two multivariate statistical techniques was used to identify differences in
 253 the ensemble of soil properties among the four soil conditions. In more detail, the Principal
 254 Components Analysis (PCA) was applied to derive uncorrelated variables (Principal
 255 Components, PCs) from the original dataset of observations (Lee Rodgers and Nicewander,
 256 1988). First, the original variables (expressed by different measuring units) were standardized,
 257 when necessary, and Pearson's method was used to compute the correlation matrix. The first
 258 three PCs, explaining at least 70% of the variance of the original variables, were considered.
 259 Then, the observations were grouped in clusters using the Agglomerative Hierarchical Cluster
 260 Analysis (AHCA), a distribution-free ordination technique to group samples with similar
 261 characteristics by considering an original group of variables. Euclidean distance was used as the
 262 similarity-dissimilarity measure.
 263 The statistical analysis was carried out using the XLSTAT release 19.1 (Addinsoft, Paris,
 264 France) software.

265

266 3. Results

267

268 The one-way ANOVA revealed that, of the studied physico-chemical properties of soil, only clay
 269 contents, SHC, EC, and OC were significantly different among the four soil conditions ($p < 0.05$)
 270 (Table 1).

271

272 Table 1 – Results of one-way ANOVA applied to physico-chemical properties of soils under
 273 four soil conditions (banqueting, dry farming, abandoned dry farming and natural rangeland) in
 274 the experimental site (Khangah Sorkh, West Azerbaijan, Iran).

275

Soil properties	Degrees of freedom	Sum of squares	Mean squares	F	Pr > F
Sand	3	183.604	61.201	1.876	0.212
Silt		72.432	24.144	2.378	0.146
Clay		301.432	100.477	6.274	0.017
SP		238.444	79.481	2.975	0.097
BD		0.027	0.009	0.325	0.807
SWC		13.963	4.654	0.338	0.798

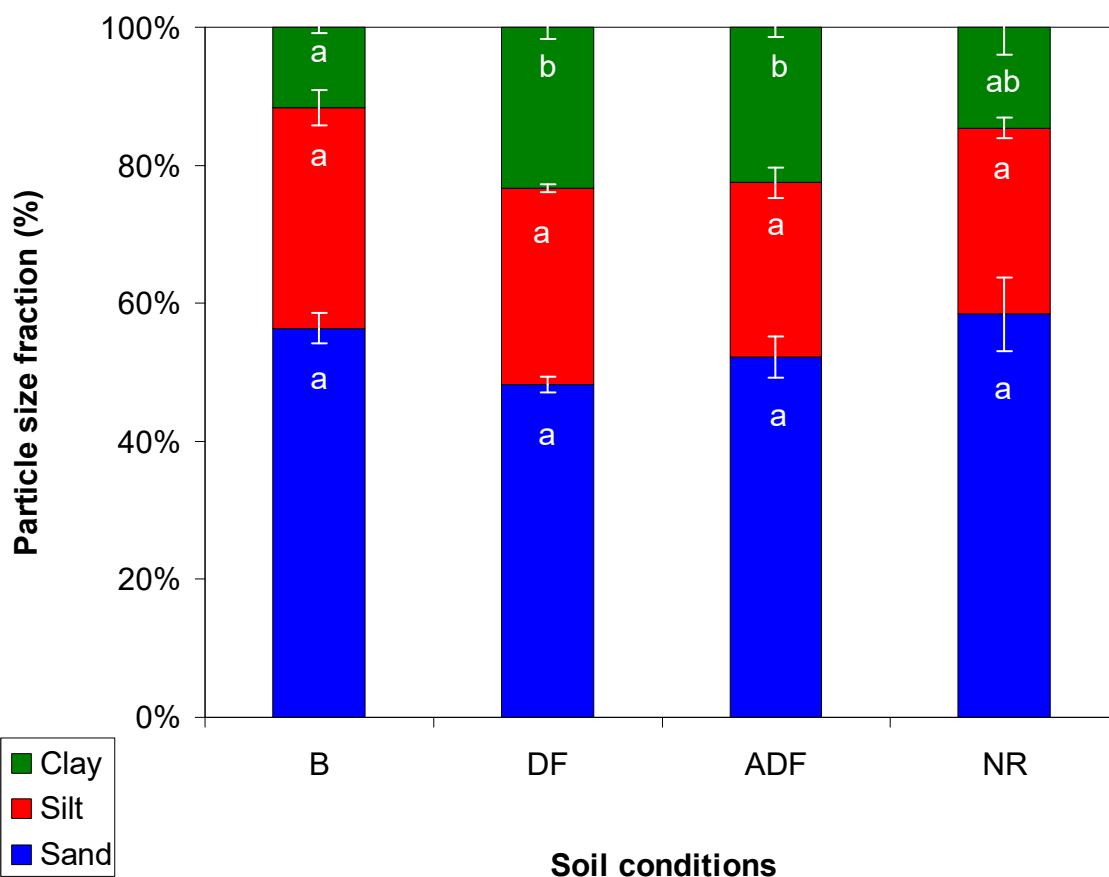
SHC	0.000	0.000	28.363	< 0.0001
pH	0.026	0.009	1.195	0.371
EC	0.121	0.040	4.780	0.034
OC	1.792	0.597	10.535	0.004
CCE	32.544	10.848	1.974	0.197

276 Note: bold characters highlight significant differences in the soil property at $p < 0.05$.

277

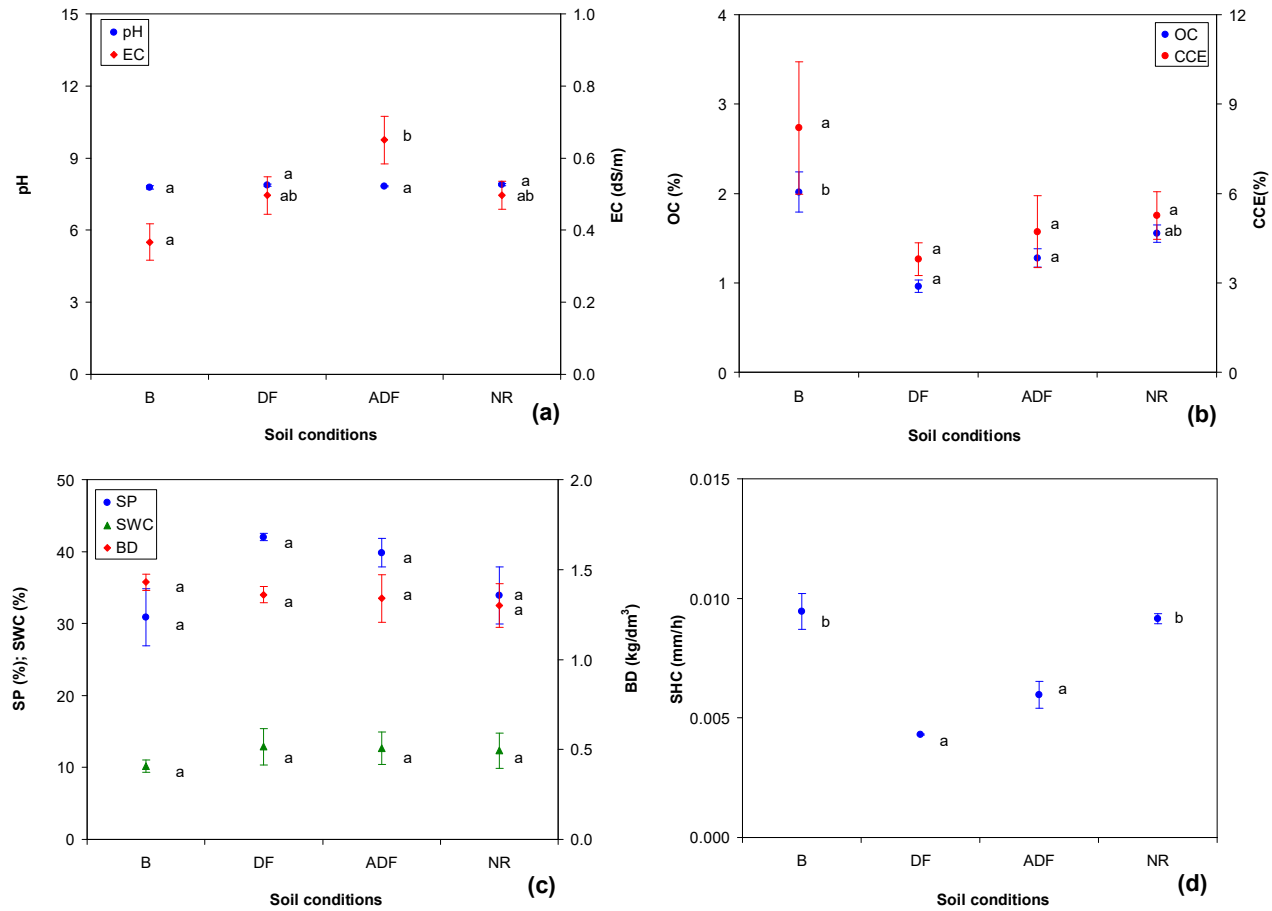
278 With regard to the soil texture, the differences between the reference plots (NR) and the three
 279 other soil conditions were never significant. In more detail, the lowest clay content was found in
 280 the soil treated with banqueting ($11.7 \pm 0.83\%$), and this value was significantly lower compared
 281 to the soils subjected to dry farming in abandoned sites ($22.5 \pm 1.44\%$, or not, $23.3 \pm 1.67\%$), but
 282 not to natural rangeland plots (14.6 ± 3.97) (Figure 3).

283



284

285 Figure 3 – Mean \pm standard error ($n = 3$ composite samples) of particle size fractions of soils
 286 under four soil conditions (B - banqueting, DF - dry farming, ADF - abandoned dry farming and
 287 NR - natural rangeland) in the experimental site (Khangah Sorkh, West Azerbaijan, Iran).



288

289 Figure 4 – Mean ± standard error (n = 3 composite samples) of physico-chemical and hydrological properties of soils under four soil conditions (B -
 290 banqueting, DF - dry farming, ADF - abandoned dry farming and NR - natural rangeland) in the experimental site (Khangah Sorkh, West
 291 Azerbaijan, Iran). Legend: SP = soil porosity; BD = soil bulk density; SWC = soil water content; SHC = soil hydraulic conductivity. Different letters indicate significant
 292 differences among the soil conditions after Tukey's test (p < 0.05).

293

294 Concerning the chemical properties of soil, banqueting gave the minimum EC (0.37 ± 0.05
 295 dS/m), while only abandoned dry farming sites showed significantly higher values (0.65 ± 0.07
 296 dS/m) (Figure 4a). Both dry farming conditions (abandoned or not) showed a lower OC content
 297 ($1.28 \pm 0.1\%$ and $0.96 \pm 0.07\%$, respectively) compared to sites subjected to banqueting (Figure
 298 4b).

299 In comparison to NR sites (SHC of $9.15 \times 10^{-3} \pm 2.03 \times 10^{-5}$ mm/h), the physical properties of
 300 soil (SP, BD and SWC) were similar among the four soil conditions (Figure 4c), while, in
 301 comparison to NR sites (SHC of $9.15 \times 10^{-3} \pm 2.03 \times 10^{-5}$ mm/h), SHC was significantly lower in
 302 dry farming plots (abandoned or not, $5.97 \times 10^{-3} \pm 5.62 \times 10^{-4}$ mm/h, and $4.3 \times 10^{-3} \pm 2.53 \times 10^{-5}$
 303 mm/h, respectively), but not in B plots ($9.45 \times 10^{-3} \pm 7.48 \times 10^{-4}$ mm/h) (Figure 4d).

304 PCA identifies three Principal Components, explaining 73.7% of the total variance in the original
 305 variables. PC1 explains 40% of this variance, while PC2 another 20.3%. All chemical properties
 306 of soils together with soil porosity and clay content have high loadings on the first PC (absolute
 307 values > 0.607), except pH, which noticeably weighs with SWC on the second PC (loading $>$
 308 0.707). Sand and silt contents show noticeable associations with PC3 (loadings over $|0.686|$),
 309 while bulk density is linked to a fourth PC (loading of 0.864), which explains another 13.1% of
 310 the total variance (Figure 5a and Table 2).

311

312 Table 2 - Factor loadings of the original variables (main physico-chemical properties of soils) on
 313 the first four Principal Components (PC1 to PC4) provided by PCA, applied to soil samples
 314 collected under four soil conditions (banqueting, dry farming, abandoned dry farming and
 315 natural rangeland) in the experimental site (Khangah Sorkh, West Azerbaijan, Iran).

316

Variables	Principal Components			
	PC1	PC2	PC3	PC4
Sand	-0.597	0.370	-0.686	0.104
Silt	-0.471	-0.042	0.869	-0.005
Clay	0.888	-0.352	0.179	-0.103
SP	0.793	-0.507	-0.185	-0.155
BD	-0.142	-0.398	0.139	0.864
SWC	0.307	0.707	0.164	-0.461
pH	0.142	0.785	0.229	0.297
EC	0.607	0.342	-0.219	0.460

OC	-0.836	-0.324	-0.040	0.044
CCE	-0.654	-0.396	-0.153	-0.366
SHC	-0.882	0.234	0.086	-0.016

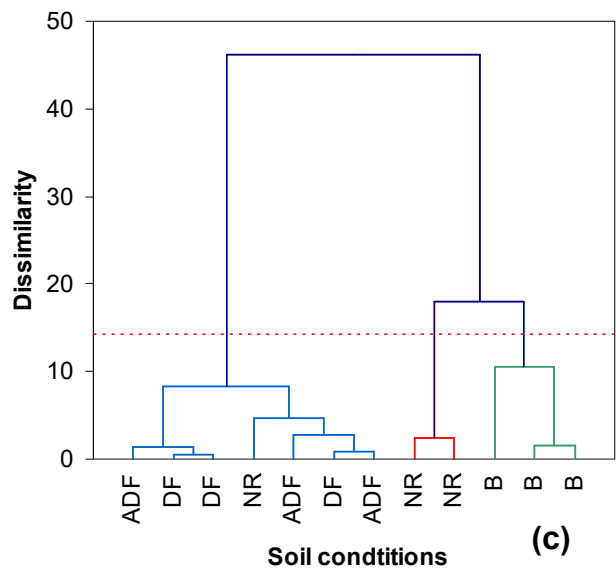
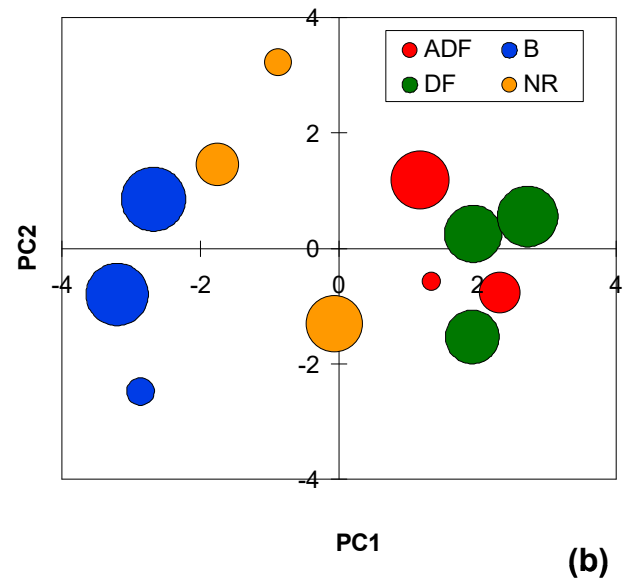
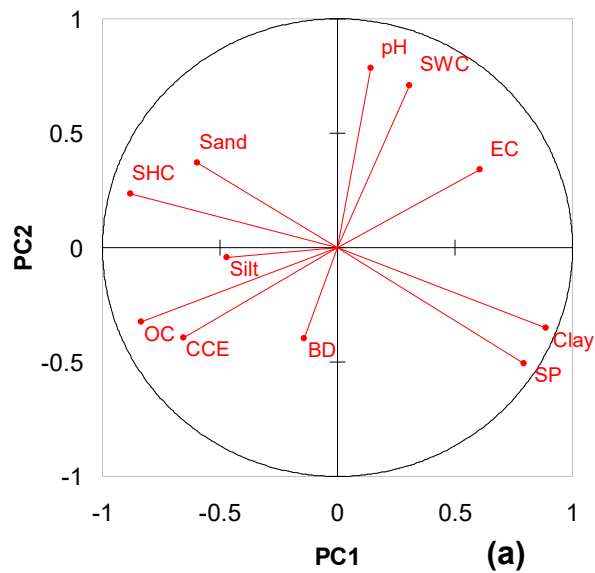
317 Notes: P = soil porosity; BD = soil bulk density; SWC = soil water content; SHC = soil hydraulic conductivity; EC
318 = electrical conductivity; OC = soil organic carbon; CCE = calcium carbonate equivalent. Note: bold characters
319 highlight significant differences in the soil property at $p < 0.05$.

320

321

322 PCA coupled to AHCA groups the soil samples in three separate clusters. In more detail, a first
323 cluster groups all samples collected in soils subjected to banqueting, a second cluster includes all
324 samples of dry farming plots (abandoned and not) as well as samples of natural rangeland, while
325 the third cluster consists of the other samples from natural rangeland (Figures 5b, 5c and 5d).

326



Clusters		
1	2	3
B	DF	NR
B	DF	NR
B	DF	(d)
	ADF	
	ADF	
	NR	

328 Figure 5 - Loadings of the original variables (main physico-chemical properties of soils) (a), scores on the first two Principal Components (PC1 and
329 PC2) provided by PCA (b), dendrogram of the original variables (main physico-chemical properties of soils) (c) and cluster composition (d)
330 provided by the Agglomerative Hierarchical Cluster Analysis (AHCA), applied to soil samples collected under four soil conditions (banqueting, dry
331 farming, abandoned dry farming and natural rangeland) in the experimental site (Khangah Sorkh, West Azerbaijan, Iran). Legend: SP = soil porosity; BD
332 = soil bulk density; SWC = soil water content; SHC = soil hydraulic conductivity; EC = electrical conductivity; OC = soil organic carbon; CCE = calcium carbonate equivalent.
333 Point diameter in figure b is proportional to the value of PC3.

334

335 **4. Discussions**

336

337 Compared to the reference soil (natural rangeland), the study evidenced that crop cultivation and
338 agricultural operations reduced significantly SHC (-44% by averaging abandoned and non-
339 abandoned dry farming areas) compared to the reference soil (natural rangeland). The general
340 reduction in water infiltration noticed in farmlands may result in increased surface runoff and
341 soil erosion in these semi-arid areas. Therefore, the hydrological response of cultivated soil
342 (abandoned or not) to intense and short rainstorm may cause flooding and hydrological hazard.
343 Important variations in the soil hydrological properties between intensely cultivated areas and
344 abandoned lands were also noticed by Lucas-Borja et al. (2019) in a similar environment. In
345 comparison to intensive agricultural areas, these authors ascribed the reduction in SHC detected
346 in abandoned lands to the finer texture.

347 Banqueting significantly counteracted the reduction measured for water infiltration. SHC, which
348 was significantly higher by 84% compared to the cultivated areas, resulted in very similar values
349 as in the natural rangeland. The SHC is very low in the site, and this is a further reason of the
350 importance of soil conservation techniques to contrast the hydrological impacts of surface runoff
351 and soil erosion. Since the slope of the longitudinal profile is reduced behind banquets, the
352 installation of these structures helps storing a higher share of rainwater compared to the
353 untreated area. Therefore, water infiltration increases, which is beneficial for plant growth and
354 recharge of seepage. Presumably, the soil management operations adopted to build the banquets
355 modified the textural conditions of soil, although the soil compaction of agricultural areas was
356 not altered (as shown by the comparable bulk density). As a matter of fact, the gradient in SHC
357 detected among the four soil conditions may be associated to the variations in the clay content of
358 soil, which is shown by the negative correlation between these two parameters (Pearson's r equal
359 to -0.78). More in general, soil texture was not modified by banqueting, as demonstrated by the
360 non-significant variations in the sand, silt and clay fractions compared to the reference condition.
361 The construction of banquets with the required operations may be a viable practice to limit soil
362 degradation in these semi-arid lands. This statement directly derives from this study, since
363 banqueting limited the increase in clay fraction measured in dry farming conditions (-49%). The
364 clay content of areas treated with banquets was even lower (-20%) compared to the reference
365 conditions. The increase in the finer particles of soil in cultivated areas requires attention, since a
366 higher clay fraction in soil may lead to a lower water infiltration (Hillel, 1998), and this is
367 confirmed by the infiltration tests in the experimental plots. The change in soil texture detected

368 in the banqueted areas, although being of small magnitude and limited to the clay fraction, could
369 be directly related to the banquet construction. This result is supported by the statistical analysis
370 that found that the variability in clay content with the soil condition was significant (in absence
371 of other external disturbances). Moreover, the action of banquets should not be comparable to
372 the effects of small check dams, which carry out a selective transport of sediments with
373 accumulation of finer fractions upstream and of coarser sediment downstream. Banquets are very
374 small structures, and a pool is not created, as generally found upstream of a check dam, and this
375 prevents a noticeable sedimentation of the finer fraction of soils upstream of banquets. In
376 contrast, it would be possible that the erosive power of water stream due to the more rapid runoff
377 downstream of the banquet (in the water stream over the berm, having a steeper slope compared
378 to the terrace upstream) have eroded the finer sediments on the soil surface, thus increasing the
379 silt and sand contents (although not significantly). Further research based on grain size analysis
380 of a significant number of samples collected very close to the banquet (e.g., terrace, berm, areas
381 out of the specific action of banquets) should confirm these statements.

382 Moreover, the effects of banquets did not impact on the other physical properties of soil
383 (porosity, water content, and bulk density), thus preserving its hydrological properties and even
384 supporting a higher water supply to the seepage. The banquets with the growing vegetation act as
385 small porous dam (fertilized island), transversely built on soils with gentler profile compared to
386 the undisturbed hillslopes. These small structures reduce the overland flow velocity and increase
387 the sedimentation of soil particles (Lucas-Borja et al., 2021). This increases organic matter and
388 nutrient contents of soil (under the dissolved form), improving its fertility and water retention
389 capacity (Manlay et al., 2007). Moreover, although not directly measured in this study, the
390 presence of banquets in sloping areas may help reducing the surface runoff and soil erosion,
391 thanks to the reduction of the longitudinal profile slope as well as to the local stabilization of soil
392 particles.

393 Regarding the chemical properties of soil, banquets were effective at reversing the significant
394 increase (+31%) measured in the soils of abandoned dry farming compared to the reference
395 condition. An increase in EC indicates a higher soil salinity, which is a detrimental effect for soil
396 health and functionality (Ferreira et al., 2022). Saline soils are characterized by a low crop
397 productivity, due to the increase in its osmotic potential (Qadir et al., 2006). Furthermore, a
398 higher salt content makes soils more prone to the degradation of their hydrological properties,
399 such as water infiltration (due to lower aggregate stability) and aggregate destructuring (due to
400 the sodicity) (Qadir et al., 2006). In contrast to what observed in the abandoned dry farming
401 plots, the increase in EC was not measured in cultivated soils (showing the same values as the

402 plots in natural rangeland), and this may be due to salt uptake by plants (Egamberdieva et al.,
403 2019). Salt leaching due to rainfall (practically equal among all soil conditions) should have
404 played a much minor role on soil EC (Letey et al., 2011). Also for this soil property, a beneficial
405 effect of banquet construction has been evidenced by the soil analysis, showing reductions in EC
406 by 26% compared to the natural rangeland, and 44% compared to the abandoned dry farming.
407 This result is surprising, since an increase in water infiltration was measured in areas with
408 banquets, and this may have supported salt leaching in the deeper layers of soil with consequent
409 decrease in EC (e.g., Carra et al., 2021). Therefore, banqueting may also be an effective strategy
410 to limit soil salinization and thus degradation in semi-arid to arid areas, as observed in the
411 experimental plots.

412 The organic matter content of soil (proportional to the OC) followed a gradient “dry farming
413 (abandoned or not)” < “natural rangeland” < “banqueting”, with the latter areas showing a
414 significantly higher content compared to the other soil conditions (+30% compared to natural
415 rangeland and even +80% compared to dry farming). This effect must be further explored, since
416 the main reason for organic matter increase in the areas upstream of transverse structures
417 (sedimentation of finer fraction of soil with dissolved organic matter) was not recorded. Also for
418 organic matter, banqueting is an effective action to preserve and even increase the OC stock in
419 semi-arid soils. Organic matter is a binding agent for soil particles, and this action is important to
420 form soil aggregate (Kavdir et al., 2004), and therefore to enhance soil infiltration. This
421 statement is confirmed by the significant correlation between OC content and SHC (0.77),
422 showing that a higher organic matter content of soils increases water infiltration. Therefore,
423 banqueting brings beneficial impacts not only on soil fertility, but also on its hydrological
424 properties, considering that high content in soil organic matter results in higher aggregate
425 stability, and therefore in higher water infiltration and resistance to soil erosion in steep lands
426 (Morbidelli et al., 2018). However, the results of studies carried out in different land uses of Asia
427 are generally contrasting about organic matter content in soils (e.g., Kalu et al., 2015; Li-jiang et
428 al., 2010). The literature is unanimous in stating that the soil’s hydrological response generally
429 improves after the application of soil conservation techniques in arid and semi-arid lands. In
430 general, the soil conservation techniques using the control of hillslope topography (e.g., terraces,
431 contour furrows, ridges, and semi-circular bunds) are highly effective to reduce surface runoff
432 and soil erosion (Li, 2000). For instance, (Taye et al., 2013) report that the runoff coefficient and
433 soil loss in rangelands and croplands of Ethiopian highlands tend to decrease with the installation
434 of soil and water conservation structures (in that study stone bunds and trenches or their
435 association). Furthermore, the response of topsoil is more and more variable under dry

436 conditions (Mayor et al., 2009). Soil management practices, such as the fertilizer application, can
437 also increase the content of nutrients in soil, but this was not observed in our study, due to the
438 low application rates of soil additives.

439 Our study did not find a significant correlation between SWC and OC content of soil (< 0.390),
440 and this is in close agreement with Shabanpour et al. (2020). In contrast, Hudson (1994) reported
441 a positive and significant correlation between these two parameters in soil with three different
442 textures (sandy, silty loam and silty clay loam). According to this author, the correlation is due to
443 the increase in field capacity of soil due to the higher organic matter content, while the
444 permanent wilting point is not affected by any changes. Specific measurements of these
445 hydrological parameters may give indications about the available water for plants in soils.

446 The multivariate analysis of soil samples collected under the different conditions using PCA
447 provided four PCs as a lower number of variables associated to soil properties. None of these
448 PCs was separately linked to a category of soil properties (e.g., physical or chemical parameters,
449 soil texture, hydrological variables), as it may be expected. However, as a result from the
450 changes in physico-chemical properties due to the soil disturbance, a clear discrimination among
451 the soil conditions has been revealed by PCA coupled to AHC. In more detail, the three clusters
452 identified by these techniques are separately related to (i) soils treated with banqueting, (ii) dry
453 farming (abandoned or not) and (iii) natural rangeland (with one exception). Considering all soil
454 parameters processed using multivariate statistics, a qualitative gradient in soil quality
455 “banqueting” $>$ “natural rangeland” $>$ “dry farming” is therefore revealed by this analysis, and
456 this gradient further proves that the installation of banquets in semi-arid areas may improve
457 many soil properties, even compared to undisturbed soils. This gradient mainly sources from the
458 significant increase in water infiltration in areas with banquets and natural rangelands, in its turn
459 associated to higher content in organic carbon compared to both abandoned and dry farmlands.
460 The gradient in soil hydrology (“natural rangeland” $>$ “dry farming”) found in this study is in
461 close agreement with findings of (Kabir et al., 2020), who reported higher hydraulic conductivity
462 of soil in rangelands of Central Iran compared to abandoned and dry farmlands, thanks to the
463 increase in soil organic carbon. Therefore, considering the beneficial effects of the latter property
464 on soil quality, the soils in rangelands with poor conditions require management techniques with a
465 substantial input of organic carbon to achieve an appropriate level of soil quality (Safaei et al.,
466 2019).

467 Overall, the use of soil conservation techniques based on topography control, such as
468 banqueting, is an important issue for land managers operating in degraded agricultural areas,
469 such as in dry countries, such as Northern Iran and Morocco, where the changes in land use have

470 been more rapid in recent year (e.g., Emadi et al., 2008; Sadeghi et al., 2007) and increases in
471 soil erosion up to intolerable rates have been recorded in badlands (Simonneaux et al., 2015).
472 Therefore, in this important agricultural context, the evaluation of soil quality and fertility, as
473 affected by intensive agriculture, is compulsory to give farmers, agronomists and land managers
474 insights about the most suitable crops and cultivation practices. Farmers, also thanks to the help
475 of agronomists and land planners, can find a potentially cheap and simple technique for soil
476 conservation in arid lands. This technique can be applied to control land degradation in croplands
477 and natural areas also under the expected scenarios of climate changes, which forecast an
478 increase in soil aridity and a decay in many soil properties. In this regard, the results of our study
479 validate this technique at least in the experimental conditions, although further verifications are
480 needed to prove the beneficial effects of banqueting under other specific conditions.

481

482 **5. Conclusions**

483

484 This study has demonstrated that soil conservation techniques based on the control of soil
485 topography (i.e., banqueting in West Azerbaijan, Iran) are able to increase water infiltration,
486 thanks to the higher organic carbon content of soil. This beneficial effect helps to reduce the
487 negative impacts of intensive cultivation and agriculture abandonment under arid conditions,
488 thus contributing to restore degraded natural rangelands.

489 Compared to reference condition (natural and undisturbed rangeland), water infiltration and
490 organic carbon content of soil were higher in areas with banquets. Moreover, a lower salinity
491 was measured in the banqueted soils compared to the cultivated areas. These effects are
492 important to enhance soil fertility and resistance to erosion on one side, and reduce soil salinity
493 on the other side. These evaluations proved the agronomic and hydrological convenience of
494 banquet construction in the different environmental contexts compared to the common land uses.
495 Therefore, banqueting may counteract the degradation of soil due to the agricultural activity and
496 its abandonment, and may restore the properties of the undisturbed soils that are typical of
497 natural rangeland, at least regarding the experimental areas.

498 In addition to the studied soil properties, other parameters should be analyzed about the impacts
499 of banqueting on soil stability, health and quality. For instance, direct measurements of runoff
500 and erosion rates (also at micro-plot or plot scales) may confirm the potential action for soil
501 conservation of banquets (only indirectly derived by this investigation). Moreover, a broader
502 approach, considering other important soil properties, such as the content of nutrients, cation
503 exchange capacity, and key biochemical parameters, may confirm whether the impacts of

504 banqueting against the decay of quality of natural resources. Measurements of permanent wilting
505 point and field capacity in rural lands may indicate changes in water availability for naturally
506 growing plants or cultivated crops.

507 Overall, in spite of the scarce adoption of this technique on the global scale (demonstrated by the
508 scarce literature in this regard), this study indicates that banqueting is a viable practice for soil
509 conservation in natural rangelands under semi-arid conditions, as for other more common
510 techniques based on the control of soil topography. This technique can be suggested for land
511 management especially in low-income areas, thanks to easy construction and low money
512 requirement for banquet construction. Therefore, the results of the study may be of help for
513 farmers, landscape managers and agronomists towards the pressing needs for soil conservation
514 and productivity in areas that are prone to degradation and abandonment. Finally, further
515 monitoring experiences of soil properties could indicate whether banqueting may be successfully
516 extended to other environmental contexts that are prone to degradation with positive impacts on
517 soil health and quality.

518

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520

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